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ABSTRACT

Volume 1 of the Australian Chemistry Test Item Bank, consisting of two volumes, contains nearly 2000 multiple-choice items related to the chemistry taught in Year 11 and Year 12 courses in Australia. Items which were written during 1979 and 1980 were initially published in the "ACER Chemistry Test Item Collection" and in the "ACER Chemistry Test Item Collection Supplement" in order to provide Victoria teachers with an immediate source of items for the "core" and "options" section of their new Year 12 course, pending publication of the item bank. The current publication contains most of the 542 items in these collections, together with hundreds of items which had not been released previously. The items are designed to assist teachers in the preparation of tests for diagnostic and achievement purposes. The introduction includes instructions on using the item bank and a content classification of the items in volumes 1 and 2. The appendix includes the item bank for (1) atomic structure, (2) electronic structure, (3) the periodic table, (4) the mole and chemical formulae, (5) molecular compounds, (6) infinite arrays, (7) gases, (8) solutions, (9) surfaces, (10) stoichiometry, (11) heat of reaction, (12) chemical equilibrium, (13) reaction rates, and (14) acids and bases. (Author/PN)

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Mr D. Williams	Princes Hill High School
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The development of items related to chemistry taught in South Australia was assisted by Mr P. Schodde, Curriculum Directorate, Education Department of South Australia.

In order to provide as complete a coverage of each topic area as possible, a number of items have been reprinted from exam papers produced by the Victorian Universities and Schools Examinations Board, Victorian Institute of Secondary Education, Public Examinations Board of South Australia and from the *Bank of Items for HSC Chemistry* published by the Education Department of Tasmania.

Each of these organizations is thanked for permission to incorporate items in this publication. Items from ACER's *Science Item Bank* and the *Series L* and *Series M Chemistry Diagnostic Tests* have also been included. A list of items from these sources is given in the Appendix.

Finally, the publishers wish to thank the Education Department of Victoria for the secondment of staff to this project from 1979 to 1981 and the teachers and students in over 200 Australian secondary schools who assisted in the trial testing of items.

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INTRODUCTION

The Australian Chemistry Test Item Bank consists of two volumes containing nearly 2000 multiple-choice items related to the chemistry taught in Year 11 and Year 12 courses in Australia. Most of the items have been written by practising teachers and all items have been trial tested in schools to obtain values of item facility. The items are designed to assist teachers in the preparation of tests for diagnostic and achievement purposes.

Items from some of ACER's earlier publications have been included in the bank, together with a number of items published by State educational authorities. Addition of this material to the bank enables a wider choice of items for major topic areas.

It is hoped that teachers will produce additional items of their own for this bank, and some notes on test construction and item writing techniques are included later. The ACER would be grateful if teachers forwarded their own original items on to the Council. It is intended that suitable items will be added to the item bank at a later date. Items should be forwarded to:

ACER Chemistry Item Bank,
PO Box 210,
Hawthorn,
Victoria 3122

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THE AUSTRALIAN CHEMISTRY TEST ITEM BANK PROJECT

During 1978 the Chemistry Standing Committee of the Victorian Universities and Schools Examinations Board suggested that a Year 12 course being introduced that year would be assisted by the provision of a collection of test items. Later in 1978, the Victorian Education Department (Secondary Division) agreed to second a practising chemistry teacher to ACER to work on the preparation of a bank of chemistry items, related not only to the Victorian course, but to chemistry courses in each of the other States. The project was placed under the direction of a committee of management comprising:

Dr J. P. Keeves and Dr J. F. Izard—representing the ACER
Mr M. Cropley—representing the Victorian Institute of Secondary Education
Mr R. Fox—representing the VISE Chemistry Subject Committee

Dr I. Wilson—representing the Chemistry Education Association
Mr P. Martin was the secondee responsible for the day-to-day management of the project during 1979
Dr C. Commons was the secondee responsible for the day-to-day management of the project during 1980 and 1981.

Items which were written during 1979 and 1980 were initially published in the *ACER Chemistry Test Item Collection* and in the *ACER Chemistry Test Item Collection Supplement* in order to provide Victorian teachers with an immediate source of items for the Core and Options section of their new Year 12 course, pending publication of the item bank. The current publication contains most of the 542 items in these collections, together with hundreds of items which have not been released previously.

Most of the items included in this publication were written by practising chemistry teachers. After an initial editing, items were reviewed by panels of teachers. These reviewing panels had the task of correcting any mistakes in content, checking the plausibility of distractors, ensuring a uniformity of terminology, and imposing a consistent format which facilitates the answering of questions. Items which were found to have problems that could not be corrected were rejected. The remaining items were re-edited in the light of the reviewing panel's suggestions, and then assembled into trial tests.

Trial testing was conducted to provide empirical evidence on the performance of the items. It also provides basic statistical data, such as the percentage of trial students who responded correctly, as an aid for teachers when selecting specific items from the collection.

Trial testing was performed at the Year 12 level in over 200 secondary schools between the months of August and October in 1979, 1980 and 1981. As far as possible, the trial tests were administered to a sample of students who had previously studied the topics for which the tests were designed. The average sample size was 113 with a range of 78 to 174 students.

Most of the items included in the bank had a point biserial correlation of 0.15 or greater. The point biserial correlation provides a measure of an item's capacity to differentiate more able students from less able students as determined from the total score on the test concerned. Items with a correlation of less than 0.15 have been included where it is believed they would be useful to teachers, and such items have been marked by an asterisk placed beside the facility value in the left hand margin of the text.

The items in the bank are intended to cover the chemistry taught at both Year 11 and Year 12 levels. Since the topics taught at the Year 11 level vary widely between schools within most States, it has only been possible to obtain reliable facility values for items at the Year 12 level. It is anticipated that these data will also provide an indication of the relative difficulties of items for students at the lower level. The practice of including items for year 11 in tests administered to Year 12 students may be a major reason for the low point biserial correlations determined for some items. A low correlation need not necessarily indicate that an item is unsuitable for inclusion in a test.

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USING THE ITEM BANK

1 Uses for the Items

A Production of diagnostic tests

A diagnostic test is one which attempts to identify learning difficulties experienced by students and enables the provision of some form of assistance in overcoming the problems that are identified. Such tests should

(a) contain a comprehensive range of items measuring the objectives of the syllabus area that is being evaluated; and

(b) enable the provision of some form of feedback to the students after they have attempted the items.

The items in the bank have been constructed so that the choice of a particular distractor will allow the teacher to determine the nature of a student's error, and to advise the student of any appropriate remedial work necessary. Common errors could be discussed in class, and written explanations of the correct response (diagnostic aids) might be provided by the teacher. The format used in this publication enables teachers to select items which are most appropriate to the emphasis that they have given to various topics.

B Production of achievement tests

An achievement test is a test designed to measure a student's achievement in a particular syllabus area with a single score. Just as for a diagnostic test, it should contain a comprehensive range of items measuring the objectives of the syllabus area being evaluated. The degree of difficulty of an item at the Year 12 level can be approximately gauged by referring to the item facilities (giving the proportion of students who responded correctly to each item during trial testing). As the collection includes items with a wide range of facilities, it is possible to prepare tests which:

(a) discriminate very well between students in the more able section of the class (using items with a low facility).

(b) discriminate well between students in the weak section of the class (using items with a high facility); and

(c) spread the students over a wide range of marks (using items with a spread of facilities, with an average facility of about 50%).

Note that facility values should be used as a guide to the relative difficulties of items rather than as an absolute standard. The values quoted in the bank are likely to be dependent upon factors such as the nature of the students participating in the trial testing, the time of year at which testing was performed and the emphasis placed on the topics in different schools.

It should be pointed out that the items in this collection alone may not be suitable for assessment of achievement, as some course objectives may be better examined using extended answer test items or practical tasks.

C Models for constructing other items

This bank provides a range of item types which could be used as models for teachers who wish to construct their own items. If items from the bank are supplemented by teacher-written items, it is suggested that the supplementary items be consistent in style. Some rules for constructing multiple choice items are outlined on page ix.

2 Preparation of Tests

In preparing a test, teachers should:

- Identify the particular syllabus areas that are to be evaluated.

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- Select items which appear to evaluate these areas.
- Write items, where necessary, to provide an adequate coverage of the areas.
- Place the items in a logical order. Group items relevant to similar syllabus areas together. If possible, place the easier items early in the test, with the more difficult items towards the end of the test.
- Place items based on the same stimulus material on the one page.
- Ensure that one item does not supply the correct response for another item.
- Check that the items are not ambiguous and that each has a correct response listed.
- Prepare an answer key.
- Ask another teacher to work through the draft, to identify errors and omissions, as well as providing a check on the answer key.

During the trial testing of items, most students completed between six to seven items every ten minutes.

3 Selecting an Item

To facilitate item identification, the items have been classified according to their content area. The content areas are listed in the *Content Axis*, which incorporates an alphanumeric coding to assist the location of items. The content code, facility and answer for each item are given beside the items in the left hand margin. The following example illustrates this format.

S6d-14
20*
E

The most abundant product from the reaction of 2 mol of chlorine with 1 mol of methane in ultraviolet light is likely to be

A CH_3Cl.
B CH_2Cl_2.
C $CHCl_3$.
D CCl_4.
E HCl.

The item is classified under the content code **S6d**. From the *Content Axis*, it can be seen that code **S6d** represents properties of alkanes, where

S = **CARBON CHEMISTRY**
6 = Alkanes
d = Properties

The item is number **14** in this particular content area.

The facility of the item is about 20 per cent (i.e. about 20 per cent of the trial group of students answered this item correctly). All facility values have been rounded to the nearest ten per cent, so that the facility actually calculated from trial test data was in the range 15-24 per cent.

The answer to the item is **E**.

The asterisk beside the facility indicates that the point biserial correlation for this item was less than 0.15 (i.e. the item did not differentiate well between the more able and less able students as determined by the total score on the trial test).

4 Writing Additional Test Items

Multiple-choice items should incorporate the following points:

- The stem and each alternative must read grammatically when taken together.
- The problem posed or the question asked must be clearly set out in the stem.
- The whole item should be as brief as its proper presentation will allow.
- To keep the alternatives brief, incorporate the major part of the idea in the stem. The following example illustrates this point:

Poor

Chemistry is

A a science that is concerned with the relationships and characteristics of matter.
B a science that is concerned with the relationships of living organisms, etc.

Better

Chemistry is a science that is concerned with

A the relationships and characteristic of matter.
B the relationships of living organisms, etc.

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- Avoid a negative stem where possible.

  If unavoidable, either
  (a) emphasize **not**, or
  (b) use: all of the following **except** one. Which one?

- All distractors should be equally attractive to the uninformed, yet the correct alternative must be unequivocally the best.

- Avoid using 'none of the above' as a distractor.
  A preferred alternative is,
  for example: **D** neither **A**, nor **B**, nor C.

- All alternatives must be homogeneous in idea and style.
  For example: Do not mix functions and structures.

- Words such as 'all', 'never', 'always', 'only' should not be used indiscriminately.

- Information presented in the stem must be factually correct.

- Distractors must be clearly incorrect, and not merely incomplete.

For a more comprehensive treatment of test construction and item writing, see: Izard, J.F., *Construction and Analysis of Classroom Tests*, ACER 1977.

5 Symbols and Chemical Nomenclature

The topics taught in chemistry at the Year 11 and Year 12 levels in Australia vary considerably between the States and substantial differences may even be detected between the schools within a particular State at the Year 11 level. It is therefore not surprising to find a variety of symbols, units and terminology in use throughout the country.

In order to maintain some degree of internal consistency within this publication it has been necessary to select between the expressions in current use. It is anticipated that teachers will adapt items to their local needs where necessary. Some of the more interesting conventions used in this bank are described below:

(a) The ΔH of a reaction is quoted in units of kJ mol^{-1} rather than kJ. It refers to the enthalpy change *per mole of the reaction as written*. Thus

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l) \qquad \Delta H = -5760 \text{ kJ mol}^{-1}$$

provides the information that an enthalpy change of −5760 kJ results when 2 mol (*not 1 mol*) of butane burns completely in oxygen. At present some teachers prefer to express the unit of ΔH simply as kJ to avoid confusion.

(b) The volume unit m^3(cm^3, dm^3 etc.) has been preferred to the unit of commerce, the litre. Both units are in use in Australia, but the former unit is chosen by the majority of chemical journals.

(c) Relative atomic masses and relative molecular masses are denoted by the symbols recommended by IUPAC: A_r and M_r, respectively. (It is acceptable to use M_r for entities that are not strictly molecular.)

(d) The symbol K is used for an equilibrium constant, except where there is a possibility of confusion between K_c (concentration basis) and K_p (pressure basis). Since the equilibrium constant for a reaction is derived from the activity of the substances participating in the reaction, strictly speaking K does not have units. Some textbooks in current use introduce K as a constant derived from experimentally determined concentrations and hence include units. Teachers using this approach may wish to attach units to the values of K quoted in some items.

(e) The spelling 'sulfur' has been adopted rather than 'sulphur', in accordance with trends in the world's chemical literature.

(f) IUPAC-recommended names are used for chemical substances where this is practicable. Systematic names are used for small organic molecules (e.g. ethene rather than ethylene, ethanoic acid rather than acetic acid), in line with current practice in most Australian States. In some cases the trivial names are also given.

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CONTENT AXIS
Volumes 1 and 2

Volume 1

A ATOMIC STRUCTURE

- **A1** The nuclear atom
- **A2** Elementary particles
- **A3** Ions
- **A4** Atomic number, Elements
- **A5** Mass number
- **A6** Nuclide notation
- **A7** Isotopes
- **A8** Nuclear binding energy
- **A9** Nuclear reactions
  - **A9a** Balancing nuclear reactions
  - **A9b** Nuclear reactions in stars

B ELECTRONIC STRUCTURE OF ATOMS

- **B1** Shell structure
- **B2** Subshells, Orbitals
- **B3** Pauli principle
- **B4** Electronic configuration of atoms
- **B5** Emission and absorption spectra *(see also* **R4b** *Flame tests)*
- **B6** Ionization energy
  - **B6a** Definition
  - **B6b** Periodic variation
  - **B6c** Successive ionization energies (evidence for shells)

C THE PERIODIC TABLE

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- **C2** Organization of the periodic table *(see also* **Z1** *Transition metal characteristics)*
- **C3** Dependence of properties on electronic structure
- **C4** Periodic properties of elements *(see also* **B6** *Ionization energy* **E6** *Electronegativity)*
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D THE MOLE AND CHEMICAL FORMULAE

- **D1** Relative atomic mass
- **D2** Mass spectra
- **D3** The mole
- **D4** The Avogadro constant
- **D5** Molar mass
- **D6** Percentage composition
- **D7** Law of definite (multiple) proportions
- **D8** Empirical formulae
- **D9** Molecular formulae

E MOLECULAR COMPOUNDS

- **E1** Electronic structure and formulae
- **E2** Common molecular compounds

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- **E3** Electronic structure of molecules
- **E4** Molecular shapes
- **E5** Bond dissociation energy
- **E6** Electronegativity
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- **E9** Dispersion forces
- **E10** Permanent dipoles, Hydrogen bonds Ion-dipole bonding (see **Z2** Metal complexes)
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- **F4** Miscellaneous bonding items

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- **G2** Molecular speeds
- **G3** Relationship between pressure and volume
- **G4** Relationship between temperature and volume (or pressure)
- **G5** Molar volume
- **G6** General gas equation
- **G7** Density
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- **H3** Conductivity of electrolytes
  (see also **F2c** *Properties of ionic compounds*
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- **H4** Saturation
- **H5** Solubility
- **H6** Factors affecting solubility
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- **H7** Concentration (molarity)
- **H8** Solubility of gases in liquids

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I SURFACES

- **I1** Interfaces
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- **I3** Emulsions
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- **I7** The liquid-solid interface (wetting, meniscii)
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- **J5** Mass - mass relationships
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- **J8** Mass - gas volume relationships
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- **K2** Uses of exothermic reactions
- **K3** Temperature changes during reactions
- **K4** Units of energy
- **K5** Enthalpy change
- **K6** Calorimetry
- **K7** Thermochemical cycles

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- **L2** The equilibrium constant, K_c
- **L3** Calculations in equilibrium systems
- **L4** Effect of addition of reactants or products
- **L5** Effect of volume or pressure changes
- **L6** Effect of temperature changes
  (see also **U2b** *Preparation of ammonia*
  U3c *Properties of nitrogen oxides*
  U4a *Preparation of nitric acid*
  X2 *Sulfur oxides*
  X3 *Sulfuric acid)*
- **L7** Effect of catalysts
  (see also **M5** *Catalysis)*
- **L8** Manipulation of equilibrium constants
- **L9** Heterogeneous equilibria

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M REACTION RATES

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M2 Units of rate
M3 Stoichiometry and reaction rates
M4 Activation energy
M5 Catalysis
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M6 Reaction mechanisms
M6a Rate laws, Order, Molecularity
M6b Electrophiles, Nucleophiles
M6c Electrophilic substitution reactions
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M6e Free radical reactions
(see also **S6d** *Properties of alkanes)*

N ACIDS AND BASES

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N2 H_3O^+ concentration in acid solutions
N3 Strengths of acids and bases
Dilution of acids (see **H7** Concentration (molarity))
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N6 Ionic product, K_w
N7 pH
N8 Stoichiometric calculations involving acid-base reactions
(see also **J** *Stoichiometry)*
N9 Equivalence point, End point
Standard solutions (see **R4c** Standard solutions, Primary standards)
N10 Sources of errors in titrations
N11 Titration curves
N12 Indicators
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N14 Acidity constant, K_a

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Volume 2

O REDOX REACTIONS

P ELECTROCHEMICAL CELLS

Q ELECTROLYSIS

R MEASUREMENT AND CHEMICAL TECHNIQUES

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R4 Analysis techniques

- **R4a** Chromatography
- **R4b** Flame tests
  Emission and absorption spectroscopy (see **B5**)
- **R4c** Melting temperature determination
- **R4d** Gravimetric analysis
  (see also **J** *Stoichiometry)*
- **R4e** Standard solutions, Primary standards
  Titrations (see **J6** Reactions in solution, **N** Acids and Bases, **R4e** Standard solutions, Primary standards)

S CARBON CHEMISTRY

S1 The element

S2 Hydrocarbons

- **S2a** Composition
- **S2b** Occurrence (oil, coal, natural gas)
- **S2c** Fractional distillation
- **S2d** Cracking

S3 Functional groups

S4 Homologous series

S5 Isomerism

S6 Alkanes

- **S6a** Nature
- **S6b** Nomenclature
- **S6c** Structure
- **S6d** Properties
  (see also **M6e** *Free radical reactions)*

S7 Alkenes

- **S7a** Nature
  Preparation (see **S2d** Cracking)
- **S7b** Structure
- **S7c** Properties

S8 Alkynes

S9 Aromatic hydrocarbons

- **S9a** Nature
- **S9b** Structure
- **S9c** Properties

S10 Halohydrocarbons

- **S10a** Preparation (see **M6e** Free radical reactions, **S6d** Akane properties, **S7c** Alkene properties)

S11 Alcohols

- **S11a** Nature
  Preparation (see **S7c** Alkene properties, **S10** Halohydrocarbons)
- **S11b** Properties

S12 Aldehydes, Ketones

- **S12a** Nature
- **S12b** Nomenclature
- **S12c** Structure
- **S12d** Preparation
  (see also **S11b** *Alcohol properties)*
- **S12e** Properties

S13 Carboxylic acids

- **S13a** Nature
  Preparation (see **S11b** Alcohol properties)
- **S13b** Properties
  (see also **U7** *Amides)*

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S14 Esters

S14a Nature
S14b Nomenclature
Preparation (see **S13b** Carboxylic acid properties)
S14c Properties

S15 Fats, Oils, Detergents

S15a Nature, Structure
S15b Properties
(see also **18** *Surfactants (detergency, froth floation))*

S16 Carbohydrates

S16a Sugars
S16b Respiration
S16c Photosynthesis
S16d Starch, Cellulose
S16e Fermentation

S17 Insecticides

S18 Polymers
(see also **S16d** *Starch, Cellulose*
T2 *Silicon polymers*
U9 *Proteins*
U10 *Nucleic acids)*

S18a Monomers, Copolymers, Polymer properties
S18b Addition polymers
S18c Condensation polymers
S18d Cross linked polymers
S18e Rubber

S19 Carbon dioxide

S19a Production
(see also **S16b** *Respiration*
S16e *Fermentation)*
S19b Properties

S20 Carbonates, Hydrogen carbonates

S20a Occurrence
S20b Properties, Uses
S20c Hard water

S21 Carbon monoxide

T SILICON CHEMISTRY

T1 Silanes
T2 Silicon polymers
(see also **S18** *Polymers)*
T3 Silicon carbide
(see also **F1** *Covalent network solids)*
T4 Silicon dioxide

T4a Occurrence
T4b Structure
(see also **F1** *Covalent network solids)*
T4c Properties

T5 Silicates

T5a Occurrence
T5b Glass
T5c Clays, Ceramics, Portland cement

U NITROGEN CHEMISTRY

U1 The element

U1a Occurrence
U1b Production
U1c Properties

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U2 Ammonia

- U2a Structure
- U2b Preparation (*see also* **L** *Chemical equilibrium*)
- U2c Properties (*see also* **E10** *Permanent dipoles, Hydrogen bonds*
  Z2c *Ion-dipole bonds*
  Z6 *Metal hydroxides*)

U3 Nitrogen oxides

- U3a Occurrence
- U3b Preparation
- U3c Properties (*see also* **L** *Chemical equilibrium*)

U4 Nitric acid

- U4a Preparation
- U4b Properties

U5 The nitrogen cycle

U6 Amines

- U6a Preparation
- U6b Properties

U7 Amides (*see also* **U9c** *Urea*)

U8 Amino acids

- U8a Identity, Structure
- U8b Properties
- U8c Role in biochemical systems

U9 Proteins

- U9a Structure
- U9b Properties
- U9c Urea
- U9d Enzymes

V PHOSPHORUS CHEMISTRY

V1 The element

- V1a Occurrence
- V1b Structure
- V1c Preparation
- V1d Properties

V2 Phosphorus oxides and oxo acids

V3 Phosphates

W OXYGEN CHEMISTRY

W1 The element

W2 Water (*see also* **H** *Solutions*
N *Acids and bases*
E10 *Permanent dipoles, Hydrogen bonds*)

W3 Hydrogen peroxide

Carbon dioxide (see **S19**)
Carbon monoxide (see **S21**)
Silicon dioxide (see **T4**)
Nitrogen oxides (see **U3**)
Phosphorus oxides (see **V2**)
Sulfur oxides (see **X2**)
Metal oxides (see **Z4**)

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X SULFUR CHEMISTRY

- **X1** The element
- **X2** Sulfur oxides
- **X3** Sulfuric acid
- **X4** Hydrogen sulfide

Y HALOGEN CHEMISTRY

- **Y1** The elements
  - **Y1a** Structure
    Preparation (see **O2** Examples of electrolysis)
  - **Y1b** Properties
- **Y2** Hypohalites
- **Y3** Metal halides

Z METALS

(see also **F3** *Metallic solids)*

- **Z1** Transition metal characteristics
  (see also **C2** *Organization of the periodic table)*
- **Z2** Metal complexes
  - **Z2a** Ligands
  - **Z2b** Formulae
  - **Z2c** Ion-dipole bonds
    (see also **U2c** *Ammonia properties*
    W2 *Water)*
  - **Z2d** Solubility
  - **Z2e** Stability
- **Z3** Metal hydrides
- **Z4** Metal oxides
  - **Z4a** Preparation
  - **Z4b** Properties
- **Z5** Corrosion
- **Z6** Metal hydroxides
  Metal sulfides (see **X4** Hydrogen sulfide)
  Activity series of metals (see **O5**)
- **Z7** Occurrence of metals and metal ores
- **Z8** Ease of extraction of metals
- **Z9** Extraction techniques
  - **Z9a** Mineral dressing (froth flotation)
    (see also **I8** *Surfactants (detergency, froth flotation))*
  - **Z9b** Roasting
  - **Z9c** Leaching
  - **Z9d** Solvent extraction
  - **Z9e** Electrowinning
- **Z10** Iron extraction
  - **Z10a** Methods
  - **Z10b** Types of iron
- **Z11** Steel manufacture
  (see also **F3d** *Alloys)*
- **Z12** Copper extraction
  - **Z12a** Pyrometallurgical methods
  - **Z12b** Electrorefining
  - **Z12c** Hydrometallurgical methods, Electrowinning
    (see also **Q2** *Examples of electrolysis)*

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Z13 Nickel extraction
(see also Q5 Calculations using the Faraday constant)
Z14 Zinc extraction
Z15 Aluminium extraction
(see also Q5 Calculations using the Faraday constant)
Z16 Uranium extraction

APPENDIX

A number of items published by Australian educational authorities have been included in the bank in order to provide a more complete coverage of each of the topics in the *Content Axis*. These items and their sources are listed below. In some cases items have been modified to suit the format of the bank. Other items have been modified in accordance with suggestions from teachers or in the light of trial test data. ACER is grateful for the permission of each authority to use these items in this publication.

Bank of Items for HSC Chemistry, Levels III and Division I, Education Department of Tasmania — 79 items

A9a-6, B6b-4, B6c-5, C2-10, C3-3, C4-5, C4-6, D8-8, F2e-11, F3a-5, G4-6, G4-7, G4-8, G5-8, G8-2, G8-3, G8-4, G9-6, G10-1, G10-4, K2-3, K5-2, M1-2, M3-1, M3-2, M5-4, M5-5, M5-6, N1-8, N3-10, N3-14, N3-15, N7-4, N7-16, N7-17, N12-1, N12-2, N12-3, N12-4, N14-4, N14-5, N14-7, N14-14, N14-15, O2-12, O6-2, O6-6, O6-7, O6-8, O7-6, O7-10, O7-21, R4a-15, R4a-16, R4a-17, R4a-18, R4a-19, S6a-6, S6d-4, S7c-2, S8-1, S9c-1, S9c-7, S10-5, S11b-7, S11b-8, S11b-12, S11b-15, S12a-2, S12e-1, S13b-2, S13b-3, S13b-4, S13b-7, S13b-10, S14a-1, U7-1, X4-9, X4-10

Victorian Institute of Secondary Education and Victorian Universities and Schools Examination Board exam papers — 163 items

A3-1, A5-1, A8-1, A8-5, A9b-1, A9b-7, B3-1, B4-4, C2-3, C2-6, C2-12, C4a-2, C4a-3, C4a-4, D2-5, D2-19, D5-10, D7-3, E3-7, E4-1, E4-2, E4-5, E4-7, E4-8, E4-9, E4-15, E4-18, E5-1, E6-1, E6-5, E6-6, E9-5, E10-2, E10-3, E10-5, F1-2, F1-3, F1-6, F1-11, F2b-6, F2d-3, F2d-4, F2e-7, F3a-3, F3b-2, G1-2, G4-12, G5-11, G7-1, G7-2, G9-1, G9-2, H1-2, H1-4, H2-1, H3-2, H6-3, H7-1, H7-13, I2-4, J4-3, J4-6, J6-6, J6-7, J6-15, J8-12, J8-15, J8-16, J8-17, J9-1, K1-2, K5-7, K7-2, K7-3, K7-4, K7-5, K7-6, K7-7, K7-8, L3-9, L6-2, L6-12, N1-1, N7-22, N8-9, N8-12, N10-5, N12-7, N12-8, N12-9, N12-10, N14-8, N14-9, N14-10, N14-11, N14-16, N14-17, N14-18, O1-4, O3-4, O5-6, O6-3, O6-4, O7-2, O7-3, O7-4, O7-5, O7-12, O7-13, O7-14, P4-7, P5-2, P5-3, P5-4, P6-4, Q3-3, Q3-4, Q4-2, R1d-5, S5-2, S5-8, S9a-2, S11a-2, S11b-1, S11b-5, S11b-11, S11b-16, S12d-1, S12e-2, S16a-2, S16b-2, S19b-12, S19b-16, S21-2, S21-5, T4c-1, T4c-4, T5c-2, U2b-2, U2b-3, U2c-3, U3a-3, U3c-17, U4a-1, U9a-2, U9d-3, U10-3, U10-6, U10-12, V1b-4, V2-7, W2-5, X2-6, X2-14, Z1-8, Z1-9, Z3-4, Z3-7, Z3-8, Z3-9, Z4b-1, Z6-3, Z8-9

The Public Examinations Board of South Australia exam papers — 13 items

E4-11, E7-5, F2c-10, F2c-11, F2c-12, F2c-13, F2c-14, F2c-15, F2c-16, F2d-5, G4-5, O2-9, O2-10

The Australian Science Item Bank, Book 2, ACER — 63 items

A1-1, A2-2, A5-2, A7-3, A9a-8, B5-2, C2-1, C3-1, D5-9, F2b-4, F3c-3, G1-3, G1-4, G11-7, H4-1, H4-2, H4-4, H4-5, H5-9, H5-10, H5-11, H5-12, H5-13, H8-1, H8-2, J2-2, J2-3, L1-2, M1-5, N7-8, Q4-4, Q4-5, R2a-1, R2c-3, R2c-4, R2c-5, R4a-1, S2a-1, S2c-4, S2d-1, S2d-7, S6d-3, S6d-10, S16e-7, S16e-8, S16e-9, S16e-10, S19a-2, S19a-3, S19b-5, S19b-6, S19b-7, S19b-8, S19b-10, S19b-11, S19b-13, S20b-6, S20c-3, U2b-1, U2c-1, X2-8, X2-9, X2-10

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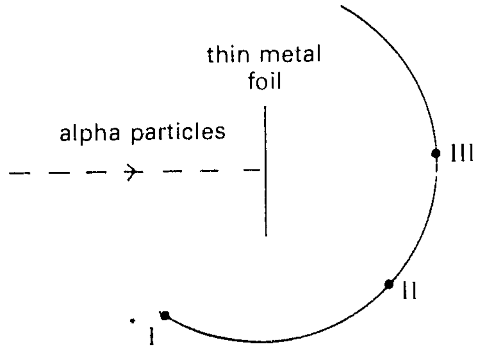
A ATOMIC STRUCTURE

ERIC

A ATOMIC STRUCTURE

A1 The nuclear atom

A1-1 The diagram below represents alpha particles being fired at metal foil 0.002 mm thick. The particles can then be detected on the curved screen.
60
C



After striking the metal foil, at which one of the points on the screen labelled I, II, III would the greatest number of alpha particles be expected to hit?

A I
B II
C III
D The number of alpha particles hitting each point would be approximately the same.

A1-2 In an experiment that was to become famous, Ernest Rutherford exposed a sheet of gold foil 0.003 mm thick to a beam of alpha particles. He observed that
90
D

A all the alpha particles were deflected through wide angles by the foil.
B a few of the alpha particles passed directly through the foil.
C all the alpha particles passed directly through the foil.
D most of the alpha particles passed directly through the foil, but a few were deflected through wide angles.

A1-3 Most of the mass of an atom is believed to be contained in a small nucleus. This is best shown by the
80
A

A passage of alpha particles through thin metal sheets.
B ease with which gases can be compressed.
C passage of light through glass.
D ease with which two gases can be mixed.

A2 Elementary Particles

A2-1 Which **one or more** of the following species may be found in the nucleus of atoms?
90
D, E

A photon
B electron
C ion
D proton
E neutron

A2-2 In which one of the following groups does the particles have approximately the same mass?
90
D

A a proton and an electron
B a neutron and an electron
C an electron and a hydrogen atom
D a hydrogen atom and a proton

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A3 Ions

A3-1 70 **D**

When a chloride ion becomes a chlorine atom

A ionization of the atom has occurred.
B the outer shell of the atom now has eight electrons.
C the ion has been reduced.
D the ion loses an electron.

A3-2 90 **B**

Which one of the following represents a cation?

A e^- **B** Li^+ **C** Cl^- **D** H

A3-3 50 **C**

The composition of two particles is given below.

particle I 22 protons 22 neutrons 20 electrons
particle II 21 protons 22 neutrons 20 electrons

The particles would best be described as

A allotropes.
B isotopes.
C cations.
D anions.

A4 Atomic number, Elements

A4-1 80 **B**

An element is a substance which consists of

A atoms of identical mass.
B atoms which have the same number of protons.
C atoms, all of which are exactly the same.
D aggregates of single atoms only, not molecules.

A4-2 70 **C**

The atomic number of an element is equal to

A the number of protons plus neutrons in a neutral atom of the element.
B the number of neutrons in a neutral atom of the element.
C the number of electrons in a neutral atom of the element.
D the weighted mean of the isotopic masses of the element.

A4-3 90* **A**

The following integers comprise a list of the atomic numbers of five elements:

5, 9, 13, 16, 18.

Which one of the following lists contains these five elements?

A aluminium, fluorine, sulfur, boron, argon
B silicon, fluorine, chlorine, boron, argon
C silicon, nitrogen, sulfur, carbon, chlorine
D aluminium, neon, chlorine, beryllium, potassium

A4-4 70 **D**

If a neutral atom of an element has 91 neutrons and 40 electrons, its atomic number is

A 131. **B** 91. **C** 51. **D** 40.

A4-5 90 **B**

The total number of electrons in a positive, doubly-charged ion of an atom of an element with atomic number 12 is

A 8. **B** 10. **C** 12. **D** 14.

A4-6 80 **B**

An ion has 9 protons, 10 neutrons and 8 electrons.
The ion is

A F^-. **B** F^+. **C** Ne^{2+}. **D** Ne^+. **E** O^+.

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A5 Mass number

A5-1 Which one of the following correctly defines the mass number of a given atom?
60
D

- **A** the total mass of neutrons and protons in the nucleus of the atom
- **B** the total mass of neutrons, protons and electrons in the atom
- **C** the number of protons in the nucleus of the atom
- **D** the total number of neutrons and protons in the nucleus of the atom

A5-2 Which of the following relationships between the atomic number (Z) and the neutron number (N) is usually correct for stable nuclei of $Z > 20$?
40
B

A $N = Z$ **B** $N > Z$ **C** $N < Z$ **D** $N = 2Z$

A6 Nuclide notation

A6-1 The species $^{35}_{17}Cl$ contains
90*
A

- **A** 18 neutrons and 17 protons.
- **B** 17 neutrons and 35 protons.
- **C** 17 neutrons and 18 protons.
- **D** 35 neutrons and 17 protons.

A6-2 An atom of rubidium $^{85}_{37}Rb$ is ionized to yield the Rb^+ ion.
90 In this ion, there are
F

- **A** 85 neutrons.
- **B** 85 electrons.
- **C** 85 protons.
- **D** 37 neutrons.
- **E** 37 electrons.
- **F** 37 protons.

A6-3 Consider an atom of uranium $^{235}_{92}U$, and suppose that the atom is ionized yielding the U^{3+} ion. In this
80 ion there are
B

- **A** 92 neutrons in the nucleus.
- **B** 89 electrons in orbitals surrounding the nucleus.
- **C** 89 protons in the nucleus.
- **D** 95 electrons in orbitals surrounding the nucleus.

A6-4 The number of electrons in the species $^{59}_{27}Co^+$ is
60
A

A 26. **B** 27. **C** 28. **D** 31.

A6-5 The number of neutrons in the species $^{64}_{29}Cu^{2+}$ is
90
C

A 27. **B** 29. **C** 35. **D** 64.

A6-6 A bromide ion is composed of 36 electrons, 35 protons and 44 neutrons. The ion is represented by the
90* symbol
D

A $^{44}_{35}Br^-$. **B** $^{80}_{36}Br^+$. **C** $^{80}_{35}Br^-$. **D** $^{79}_{35}Br^-$. **E** $^{79}_{36}Br^-$.

A7 Isotopes

A7-1 ^{12}C and ^{14}C are regarded as isotopes of the same element because
70
C

- **A** their atoms have similar physical properties.
- **B** their atoms have the same mass number.
- **C** their atoms have six protons in their nuclei.
- **D** their atomic numbers differ.

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A7-2 Isotopes can be described as atoms with the same
50
C

A mass number but different relative atomic mass.
B relative atomic mass but different mass numbers.
C nuclear charge but different mass numbers.
D mass number but different relative atomic mass.

The next two items refer to the following information

The table below indicates the number of protons, neutrons and electrons present in each of 5 atomic entities.

atomic entity	electron number	proton number	neutron number
I	6	6	8
II	7	7	7
III	8	7	7
IV	8	8	8
V	8	8	10

A7-3 Which two entities are isotopes of the same element?
70
A

A IV and V **B** II and III **C** III and IV **D** I and IV

A7-4 If X were the chemical symbol of atomic entity III, the entity would be represented by the symbol
70
A

A $^{14}_{7}X$. **B** $^{15}_{7}X$. **C** $^{15}_{8}X$. **D** $^{14}_{8}X$.

A7-5 Which one of the following groups contains isotopes of an element?
90 (The letters *J, K, L, M, Q, R, T, Z* represent the symbols of nuclei.)
C

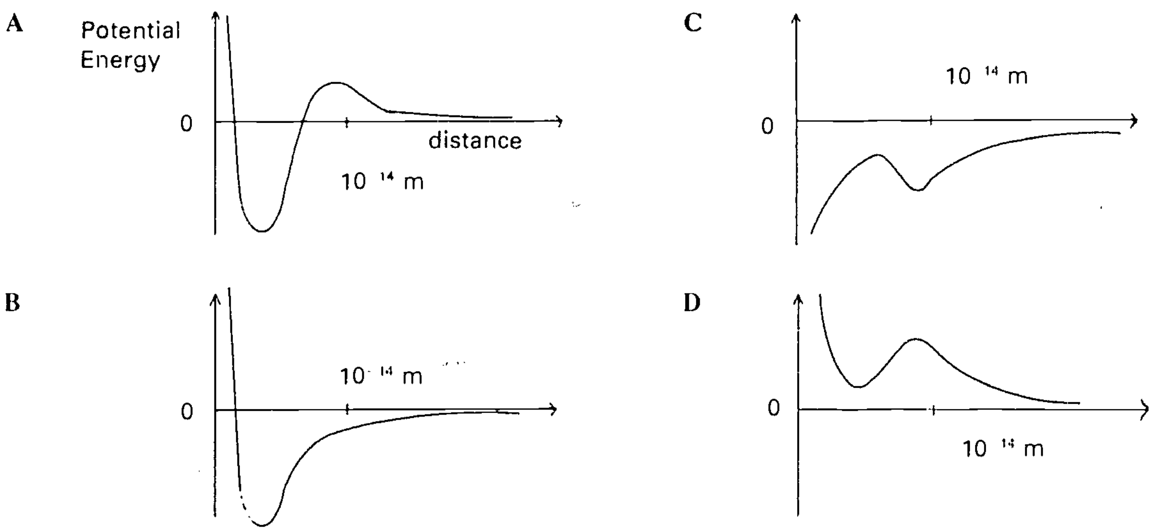
A $^{10}_{5}J$ and $^{11}_{4}K$ **C** $^{54}_{26}Q$ and $^{50}_{26}R$
B $^{32}_{17}L$ and $^{32}_{18}M$ **D** $^{64}_{30}T$ and $^{65}_{31}Z$

A8 Nuclear binding energy

A8-1 An important step in the overall nuclear reaction which goes on in the core of some stars is the production
70 of a deuteron and a positron, from the collision of two protons.
A

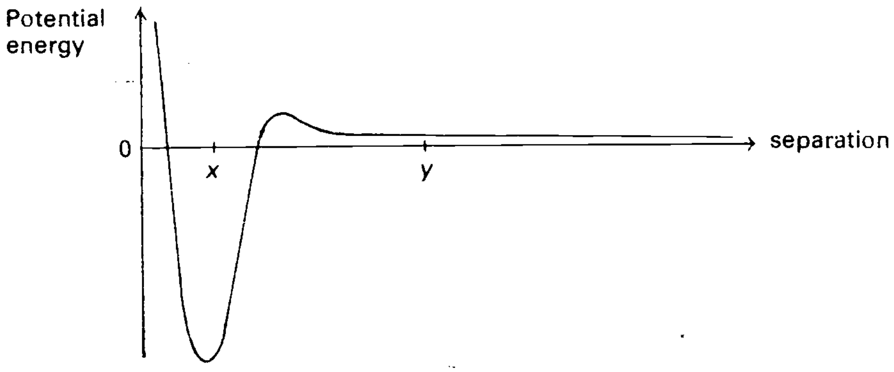
$$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + ^{0}_{1}e$$

Which of the following graphs best represents a plot of energy against distance between the two nucleons (protons) as they approach each other and ultimately react to give the deuteron and positron?



The next two items refer to the following information

The graph below shows the relationship between the potential energy of two protons and their distance apart.



A8-2 The predominant force acting between two protons separated by distance x is
30
C

A electrostatic attraction.
B electrostatic repulsion.
C strong nuclear attraction.
D strong nuclear repulsion.

A8-3 The predominant force acting between two protons separated by distance y is
40
C

A gravitational attraction.
B electrostatic attraction.
C electrostatic repulsion.
D strong nuclear attraction.
E strong nuclear repulsion.

A8-4 The nuclear binding energy of $^{4}_{2}He$ is the amount of energy released for the process
40*
A

A $2^{1}_{0}n + 2^{1}_{1}H \rightarrow {}^{4}_{2}He$.
B $4^{1}_{1}H \rightarrow {}^{4}_{2}He + 2^{0}_{1}e$.
C $^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He$.
D $^{3}_{1}H + {}^{1}_{1}H \rightarrow {}^{4}_{2}He$.

A8-5 An α-particle is an atomic nucleus containing two protons and two neutrons. It has a relative mass (RM) of 4.002 604 on the scale $^{12}C=12$ exactly. The SUM of the relative atomic masses of two separate protons and two separate neutrons is
60
C

A a little less than the RM of an α-particle.
B exactly the same as the RM of an α-particle.
C a little more than the RM of an α-particle.

A8-6 In which of the following processes would the total mass of reactants be greater than the total mass of products?
40
D

A preparation of diamond from graphite
B corrosion of iron
C action of sulfuric acid on limestone
D formation of beryllium from helium
E none of the above

A8-7 The nucleus of an isotope of beryllium can be formed by the following nuclear reaction.
30
B

$$4^{1}_{1}H + 2^{1}_{0}n \rightarrow {}^{6}_{4}Be$$

The mass of the beryllium nucleus would be

A greater than the mass of the protons and neutrons.
B less than the mass of the protons and neutrons.
C equal to the mass of the protons and neutrons.
D equal to the mass of the protons, neutrons, and the nuclear binding energy.

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A8-8 It is believed that in a supernova, iron nuclei break down according to the equation

20

D

$$^{56}_{26}Fe \rightarrow 13\,^{4}_{2}He + 4\,^{1}_{0}n$$

Energy is required for this process.

As a result of this process, the mass of the system would

A depend on the conditions under which the reaction took place.

B remain unchanged.

C decrease.

D increase.

The following data should be used to answer the item below

mass of a $^{4}_{2}He$ nucleus: 6.646×10^{-27} kg.

mass of a proton: 1.673×10^{-27} kg.

mass of a neutron: 1.675×10^{-27} kg.

velocity of light: 2.997×10^{8} m s^{-1}.

A8-9 The nuclear binding energy of the $^{4}_{2}He$ nucleus is

70

C

A $(1.673 + 1.675 + 6.646) \times 10^{-27} \times (2.997 \times 10^{8})^{2}$ J.

B $(1.673 + 1.675 - 6.646) \times 10^{-27} \times (2.997 \times 10^{8})^{2}$ J.

C $\{(2 \times 1.673) + (2 \times 1.675) - 6.646\} \times 10^{-27} \times (2.997 \times 10^{8})^{2}$ J.

D $\{(2 \times 1.673) + (2 \times 1.675) + 6.646\} \times 10^{-27} \times (2.997 \times 10^{8})^{2}$ J.

A8-10 The hydrogen bomb makes use of the following reaction

60

C

$$4\,^{1}_{1}H \rightarrow {}^{4}_{2}He + 2e^{+}$$

1 mol of $^{1}_{1}H$ atoms has mass $1{\cdot}007825 \times 10^{-3}$ kg.

1 mol of $^{4}_{2}He$ atoms has mass $4{\cdot}002604 \times 10^{-3}$ kg.

1 mol of e^{+} particles has mass $0{\cdot}0005486 \times 10^{-3}$ kg.

c represents the velocity of light, in appropriate units.

When 4 mol of $^{1}_{1}H$ atoms react in this manner, the energy released is

A $10^{-3}(4{\cdot}002604 + 0{\cdot}0005486 - 1{\cdot}007825)c$ Joule.

B $10^{-3}(4{\cdot}002604 + (2 \times 0{\cdot}0005486) - (4 \times 1{\cdot}007825))c^{2}$ Joule.

C $10^{-3}((4 \times 1{\cdot}007825) - (2 \times 0{\cdot}0005486) - 4{\cdot}002604)c^{2}$ Joule.

D $10^{-3}(4{\cdot}002604 + 0{\cdot}0005486 - (4 \times 1{\cdot}007825))c$ Joule.

A9 Nuclear reactions

A9-1 For a nuclear fusion to occur, two interacting nuclei must

70

C

A exert no electrostatic repulsions on each other.

B demonstrate a mutual electrostatic attraction.

C acquire sufficient kinetic energy to overcome an electrostatic repulsion.

D undergo a mass increase which accounts for the energy needed to overcome the net electrostatic repulsions.

A9a Balancing nuclear equations

A9a-1 The element mendelevium (Md) was first isolated by the bombardment of einsteinium atoms (Es) with α particles in the process

80

B

$$^{253}_{99}Es + {}^{4}_{2}He \rightarrow {}^{256}_{101}Md + X$$

The particle represented by X must be

A a proton.

B a neutron.

C an electron.

D a hydrogen atom.

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ERIC

A9a-2 60 C

One of the nuclear reactions studied by Lord Rutherford was the bombardment of nitrogen nuclei by alpha-particles. The reaction can be represented as

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{13}_{6}C + ^{1}_{1}H + X$$

The particle X is

A an electron.
B a proton.
C an alpha-particle.
D a deuterium nucleus.

A9a-3 50 C

An element X undergoes radioactive decay to produce a neutron and a group V element only. Element X is in group

A III. B IV. C V. D VI.

A9a-4 60* B

A positron is a positive particle with the same mass as

A one proton.
B one electron.
C one proton and one neutron.
D two protons and one electron.

A9a-5 50 D

An element Y undergoes radioactive decay to produce a positron and a group IV element. Element Y is in group

A II. B III. C IV. D V.

A9a-6 40 A

Nitrogen-13 undergoes radioactive decay to form carbon-13. The particle emitted in this reaction is

A a positron.
B an electron.
C a neutron.
D a helium nucleus.

A9a-7 80 D

Which of the transmutations given below results in the emission of a helium nucleus?

A $^{214}_{82}Pb \rightarrow ^{218}_{84}Po$
B $^{233}_{90}Th \rightarrow ^{233}_{91}Pa$
C $^{24}_{13}Al \rightarrow ^{24}_{12}Mg$
D $^{230}_{90}Th \rightarrow ^{226}_{88}Ra$

A9a-8 50* D

A positron may be considered to be a positive electron.
Under certain conditions, a proton within an atom may decompose to yield a neutron and a positron. The positron is ejected from the nucleus with the simultaneous release of energy.

The resulting atom will have the same

A atomic number, but a greater mass number.
B atomic number, but a smaller mass number.
C mass number, but a greater atomic number.
D mass number, but a smaller atomic number.

A9a-9 30 D

Under certain conditions a high energy photon can disappear and produce two charged particles. It can be concluded that

A a positron and a neutron are released in the process.
B one of the particles is a proton.
C the mass of the photon is equal to the total mass of the particles.
D the particles are oppositely charged.

A9b Nuclear reactions in stars

A9b-1 60 A

The heat generated by the sun is probably due mainly to

A a nuclear fusion reaction in which hydrogen is the main reactant.
B a nuclear fusion reaction in which helium is the main reactant.
C a steady gravitational collapse in which gravitational energy is converted to thermal energy.
D a chemical reaction in which hydrogen reacts with oxygen.

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A9b-2 Stars are believed to be formed when a large cloud of gas contracts in space. The first process occurring as the gas cloud **begins** to contract is that
60
B

A nuclei heavier than $^{56}_{26}Fe$ are formed in fusion reactions.
B the kinetic energy of the gas particles increases.
C fission reactions are initiated.
D endothermic nuclear reactions produce helium particles.

A9b-3 The overall nuclear reaction that provides most of the sun's energy can best be represented by the equation
40
B

A $^{4}_{2}He + 2^{0}_{1}e \rightarrow 4^{1}_{1}H$.
B $4^{1}_{1}H \rightarrow ^{4}_{2}He + 2^{0}_{1}e$.
C $^{4}_{2}He \rightarrow 2^{1}_{1}H + 2^{1}_{0}n$.
D $2^{1}_{1}H + 2^{1}_{0}n \rightarrow ^{4}_{2}He$.

A9b-4 The temperature of the sun's core is approximately 10^7 K. At this temperature,
80*
D

A hydrogen atoms in the core collapse under gravity, releasing energy.
B fission of helium occurs and energy is released.
C helium nuclei are produced by fusion processes and energy equivalent to the nuclear binding energy is absorbed.
D hydrogen nuclei combine to form helium nuclei and energy is released.

A9b-5 As a result of the nuclear fusion process occurring in the sun,
60
A

A the average mass of the nuclei in the sun is increasing.
B the sun is becoming heavier.
C the number of nuclei in the sun is increasing.
D the number of $^{1}_{1}H$ nuclei in the sun is increasing.

A9b-6 The fusion process occurring in a hydrogen bomb is triggered by the fission reaction of an atomic bomb. An atomic bomb is required in order to
40*
D

A provide a source of neutrons which initiate a chain reaction.
B produce sufficient heat to reach the ignition temperature of hydrogen.
C provide a source of $^{4}_{2}He$ particles which initiate a chain reaction.
D raise the kinetic energy of the hydrogen nuclei.

A9b-7 It is most likely that the atoms of 'heavy' elements, such as iron, have been made by nuclear reactions inside
70
D

A the earth.
B the sun.
C stars lighter than the sun.
D stars heavier than the sun.

A9b-8 Most of the universe is composed of the elements
60
C

A carbon and oxygen.
B oxygen and silicon.
C helium and hydrogen.
D hydrogen and oxygen.
E carbon and silicon.

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B ELECTRONIC STRUCTURE OF ATOMS

B1 Shell structure

B1-1 90 **D**

The electronic structure of an atom of sulfur in its lowest energy state is

A 2, 6, 6, 2. **B** 2, 6. **C** 2, 14. **D** 2, 8, 6.

B1-2 90 **B**

The electronic configuration of a neutral atom of potassium, $^{39}_{19}K$, is

A 2, 8, 9. **B** 2, 8, 8, 1. **C** 2, 8, 8, 2. **D** 2, 8, 18, 8, 3.

B1-3 70 **B**

Four sets of atoms and ions with formal charges are listed. Which set consists of atoms and ions, each with the same number of electrons in the outer shell?

A B, F^+, O, N^-, C^{2-}
B F^+, N^-, O, C^{2-}, B^{3-}
C B^{3-}, C^{2-}, N^-, O, F
D O^-, B^{3-}, F^+, C^{2-}, N^-

B1-4 70* **C**

If each of the following particles were in their lowest energy states, which set contains particles which have the same electronic configuration?

A Li^+, Na^+, K^+, Cs^+
B Li, Be, B, C
C O^{2-}, F^-, Na^+, Ne
D Ca^{2+}, K^+, Ne, Cl^-

B1-5 60 **A**

Which one of the following ions does *not* have the same electronic configuration as the rest? (Assume all ions are in their lowest energy state.)

A K^+ **B** Mg^{2+} **C** F^- **D** O^{2-}

B2 Subshells, Orbitals

B2-1 30 **D**

A subshell in an isolated atom is *best* described as a

A group of orbitals of similar shape.
B group of orbitals of identical shape.
C group of orbitals of similar energy.
D group of orbitals of identical energy.
E region of space in which an electron can move.

B2-2 80 **D**

The order of energies for the energy levels of a many-electron atom is

A 1s<2s<2p<3s<3p<4s<4p<3d<5s.
B 1s<2s<2p<3s<3p<3d<4s<4p<4d.
C 1s<2s<2p<3s<2d<3p<4s<3d<4p.
D 1s<2s<2p<3s<3p<4s<3d<4p<5s.

B2-3 50 **B**

How many orbitals are there in the 2p subshell of an atom?

A 2 **B** 3 **C** 4 **D** 5 **E** 6

B3 Pauli principle

B3-1 80 **B**

The number of electrons which can occupy an orbital in an atom is

A 2, 8 or 18, depending on which orbital is being considered.
B 0, 1 or 2.
C 2 only.

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B3-2 80 A

Which one of the following statements *best* expresses the idea of the Pauli principle?

A An orbital can never contain three or more electrons.
B An orbital must contain two electrons.
C An orbital may contain one electron.
D An orbital must always contain one or two electrons.

B4 Electronic configuration of atoms

B4-1 60 D

An element has atomic number 27.
Its ground state electronic configuration is best expressed as

A $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 4p^6\ 5s^1$.
B $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 4d^6\ 5s^1$.
C $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9$.
D $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7\ 4s^2$.

B4-2 70* D

The electron structure of a silicon atom in its ground state is

A $1s^22s^22p^4$.
B $1s^22s^22p^63s^23p^63d^4$.
C $1s^22s^22p^63s^23p^4$.
D $1s^22s^22p^63s^23p^2$.

B4-3 70 B

The electronic configuration of a Ca^{2+} ion in its lowest energy state is

A $1s^22s^22p^6$.
B $1s^22s^22p^63s^23p^6$.
C $1s^22s^22p^63s^23p^64s^2$.
D $1s^22s^22p^63s^23p^63d^24s^2$.

B4-4 70 B

The electronic structure $1s^22s^22p^63s^23p^6$ corresponds to the species

A O^{2-}. **B** S^{2-}. **C** Al^{3+}. **D** Na^+. **E** S.

B4-5 70 C

Which of the following electronic configurations does *not* represent an atom in its lowest energy state?

A $1s^2\ 2s^2\ 2p^5$
B $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$
C $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5\ 4s^1$
D $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^2$

B4-6 50 C

The electronic structures of four neutral atoms are given below. In which case is the atom in its lowest energy state?

A $1s^22s^22p^23s^2$
B $1s^22s^22p^63s^23p^63d^{10}$
C $1s^22s^22p^63s^23p^64s^1$
D $1s^22s^23s^2$

B4-7 60 E

An atom has an electron configuration which includes a partly filled p subshell and a partly filled d subshell.
The atom must be

A from a transition element.
B from a metallic element.
C from a non-metallic element.
D from a transition or a non-metallic element.
E in an excited state.

B4-8 40* C

The number of p orbitals occupied by electrons in a chlorine atom in its electronic ground state is

A 2. **B** 5. **C** 6. **D** 11.

B4-9 30* B

Which one of the following elements has atoms in which only 5 orbitals are occupied by electrons?

A B **B** F **C** Ar **D** Rb

B4-10 50 B

Which of the following elements contains atoms in which just three subshells are occupied by electrons?

A Li **B** Ne **C** Na **D** Al

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B4-11
40
D

The element vanadium has the following electronic configuration:

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^2$

A feature of this element is that it

A contradicts the Pauli principle, as the d-orbital contains 3 electrons.

B has electrons in only four different sub-shells.

C has a full outer shell of electrons.

D has two partially filled electron shells.

B5 Emission and absorption spectra

B5-1
60
A

Which of the following scientists first postulated that the sharp lines in emission spectra of elements were caused by transitions of electrons from high energy levels to low energy levels?

A Bohr
B Einstein
C Pauli
D Rutherford
E Mendeleev

B5-2
70
C

An atom which has electrons in excited energy levels may lose energy. This energy may be emitted as

A α-particles.
B positrons.
C electromagnetic radiation.
D high speed neutrons.

B5-3
80
A

The characteristic wavelengths of light produced when sodium is placed in a flame can best be explained by the fact that

A when excited to any higher energy level, atoms emit energy in specific amounts, as the electrons drop back to a lower energy level.

B when excited to any higher energy level, atoms absorb only specific amounts of energy, which correspond to light of particular wavelengths.

C atoms are only able to absorb energy in specific quantities.

D after absorbing energy, atoms release a specific amount of energy depending on the amount of substance present.

B5-4
60
D

An electron is moving in an orbital around a proton such that its average distance from the proton is 7.2×10^{-11} m. Suddenly the electron begins to move in another orbital such that its average distance from the proton is reduced to 3.6×10^{-11} m. For the electron to change orbitals in this way, the energy of the system must

A increase, and this may be accomplished by the absorption of a photon of light.

B increase, and this may be accomplished by the emission of a photon of light.

C decrease, and this may be accomplished by the absorption of a photon of light.

D decrease, and this may be accomplished by the emission of a photon of light.

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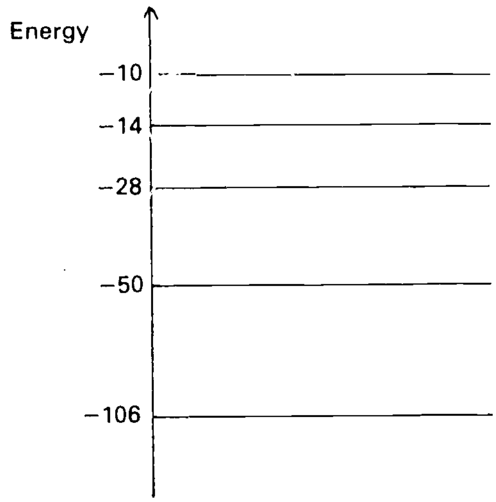
The next two items refer to the following information

The energy level diagram below shows the five lowest energy levels of an atom of a particular element. (Energy is measured in arbitrary units)



B5-5 An excited atom of this element can emit a photon with an energy of

50

A

A 36. **B** 38. **C** 42. **D** 60.

B5-6 When an atom of this element has an energy of −106 units,

80

D

A the atom has lost its highest energy electron.

B all the electrons of the atom must be in the first shell.

C the atom has been broken up into its elementary particles.

D its electrons are in the lowest possible energy levels.

B5-7 In 1814 Fraunhofer discovered that the spectrum of sunlight contains a large number of dark lines. The wavelengths of many of these lines coincide with the lines observed in emission spectra of hydrogen gas.

30

D

Light of these wavelengths is probably absent from sunlight because

A most of the light emitted from the sun is in the yellow region of the spectrum.

B hydrogen atoms are consumed in nuclear reactions in the sun.

C excited electrons within hydrogen atoms drop to lower energy levels, releasing energy.

D hydrogen atoms in or near the sun absorb light of definite wavelengths.

E atoms in the sun are completely ionized.

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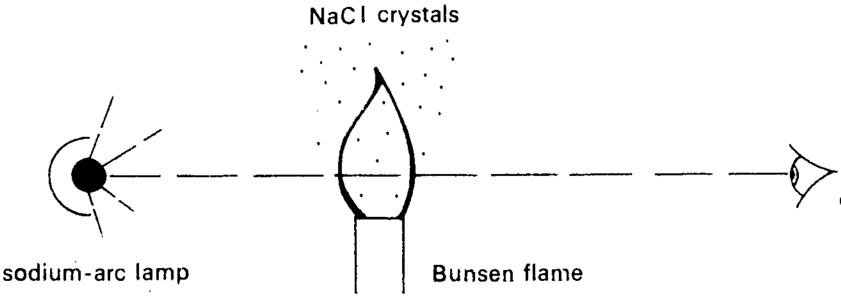
B5-8
30
A

A Bunsen flame is placed in front of the yellow beam of light from a sodium-arc lamp, as shown in the diagram below.



If a small quantity of sodium chloride crystals were sprinkled into the flame, the light passing through the flame would appear

A less intense, as sodium ions in the flame would absorb light.
B unchanged, as light would be absorbed and emitted in equal amounts.
C more intense, as light would be emitted from excited sodium ions in the flame.
D more intense, as light would be emitted from both the excited sodium and chloride ions in the flame.

B5-9
50*
B

A major advantage of atomic absorption spectroscopy as compared with flame tests in analysing chemical samples is that

A the samples do not have to be heated as strongly.
B it is possible to identify the presence of more than one element in a sample.
C it is specific for metals in Group I and II of the periodic table.
D the samples are not destroyed during the analysis.

B5-10
60
A

In order to obtain the absorption spectrum of a material in solution a 'blank' is used. The blank contains pure solvent and is mainly used in order to

A allow for absorption by the solvent.
B provide an alternative pathway for the light.
C prevent absorption by molecules in air.
D prevent excitation of solvent molecules.

B5-11
60
D

Many solutions employed in the laboratory are coloured. Which of the following statements concerning the absorption of light by solutions is **incorrect**?

A The amount of light absorbed by a solution depends on the concentration.
B The absorption of light by a solution may be used to determine the substances present.
C Red solutions absorb light in the green and blue regions of the spectrum.
D Each species in a solution absorbs light of a single wavelength.

B6 Ionization energy

B6a Definition

B6a-1
80
D

The first ionization energy of sodium is 494 kJ mol^{-1}. This means that 494 kJ of energy would be

A released when all the electrons are removed from one mole of gaseous sodium atoms.
B required in order to add one electron to each atom in one mole of gaseous sodium atoms.
C released when one electron is removed from each atom in one mole of gaseous sodium atoms.
D required in order to remove one electron from each atom in one mole of gaseous sodium atoms.

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B6a-2 80 B | The second ionization energy of magnesium is the minimum amount of energy required for the process

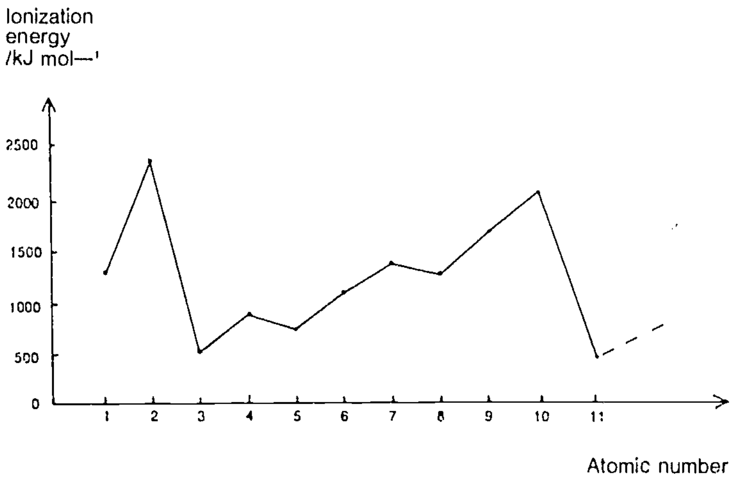
A $Mg(s) \rightarrow Mg^{2+}(g) + 2e^-$.
B $Mg^+(g) \rightarrow Mg^{2+}(g) + e^-$.
C $Mg^{2+}(g) + 2e^- \rightarrow Mg(g)$.
D $Mg(g) \rightarrow Mg^+(g) + e^-$.

B6b Periodic variation

B6b-1 60 B | The first ionization energy of an atom is the amount of energy required to just remove an electron from that atom.

Example: $H(g) \rightarrow H^+(g) + e^-$ IE = 1310 kJ mol^{-1}

When the first ionization energies of different atoms are plotted against the atomic numbers of these atoms, as shown below for the first eleven elements, two major peaks are observed.



Another major peak would be expected for

A magnesium. **B** argon. **C** chlorine. **D** silicon.

B6b-2 80 B | The first ionization energies of elements

A increase on going from left to right across a period and increase on going down a group.
B increase on going from left to right across a period and decrease on going down a group.
C decrease on going from left to right across a period and increase on going down a group.
D decrease on going from left to right across a period and decrease on going down a group.

B6b-3 50 B | Which of the following elements has the **smallest** first ionization energy?

A lithium **B** sodium **C** fluorine **D** chlorine

B6b-4 70 D | The electronic configurations for a series of neutral atoms are

I $1s^22s^1$
II $1s^22s^22p^6$
III $1s^22s^22p^63s^23p^6$
IV $1s^22s^22p^63s^23p^64s^1$
V $1s^22s^22p^5$

The atom with the **smallest** first ionization energy will be

A I. **B** II. **C** III. **D** IV. **E** V.

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B6b-5 Sodium has a lower first ionization energy (494 kJ mol^{-1}) than lithium (519 kJ mol^{-1}). This is probably because the
90
D

- **A** sodium atom has fewer electrons.
- **B** sodium electrons are at a lower energy level than the lithium electrons.
- **C** 'core charge' of the sodium atom is less than that of the lithium atom.
- **D** outer-shell sodium electrons are further from the nucleus than the outer-shell lithium electrons.
- **E** sodium nucleus has more protons than the lithium nucleus.

B6b-6
90
D

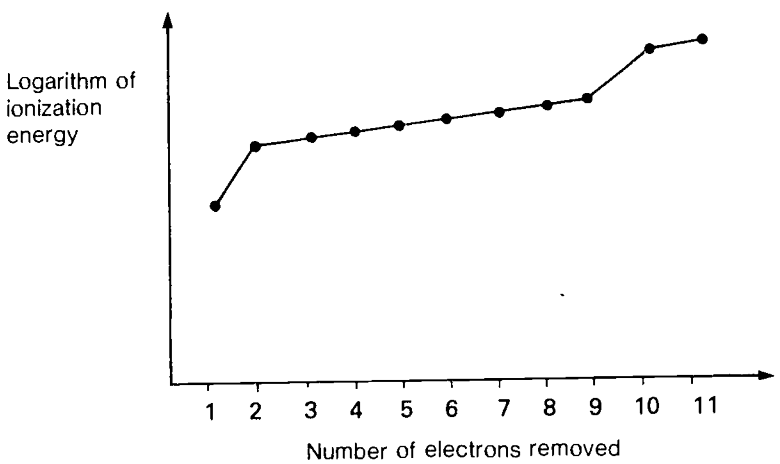
Element	*Atomic number*	*1st ionization energy in kilojoule/mole*
helium	2	2379
neon	10	2087
argon	18	1527
lithium	3	526
sodium	11	502
potassium	19	425

The above data support the proposition that

- **A** it is easier to remove the first electron from a helium atom than from a lithium atom.
- **B** as the ionization energy decreases down both groups of elements, the reactivity of these elements (with other elements) decreases in the same order.
- **C** it is easier to add an electron to an argon atom than it is to add one to a potassium atom.
- **D** helium, neon and argon have much more stable electronic structures than do lithium, sodium and potassium.

B6c Successive ionization energies (evidence for shells)

B6c-1 The following graph shows the successive ionization energies for the element sodium.
60
B



Which one of the following statements is supported by data obtainable from the graph?

- **A** Ionization energies decrease as successive electrons are removed.
- **B** In an atom, electrons are grouped in similar energy levels called electron shells.
- **C** Sodium has eleven electrons, two of which are located in the outermost electron shell.
- **D** Electrons closest to the nucleus of an atom have the lowest ionization energies.

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B6c-2
80
A

Which one of the following statements about successive ionization energies of beryllium is correct?

A The third ionization energy is very much higher than the first and the second ionization energies.
B The ionization energies increase uniformly.
C The electrons are successively easier to remove since the net positive charge is increasing.
D The lower the energy of the electron removed, the lower is the ionization energy.

B6c-3
40
B

Some of the ionization energies of an element are given below

Energy /MJ mol^{-1}		*Energy /MJ mol*$^{-1}$	
1st	1.68	5th	11.0
2nd	3.36	6th	15.1
3rd	6.07	7th	17.9
4th	8.41	8th	91.6

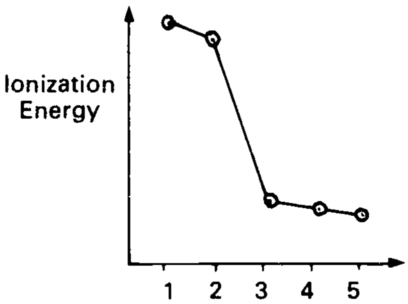
Which one of the following statements is correct?

A The element has metallic properties.
B The element is in group VII of the periodic table.
C The element would form covalent hydrides of formula XH_4.
D Atoms of the element would tend to form doubly charged ions.

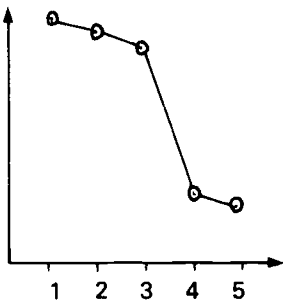
B6c-4
70
D

Which of the following graphs best represents successive ionization energies of boron (atomic number = 5)?

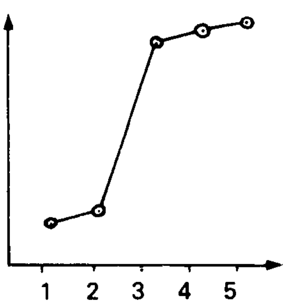
A



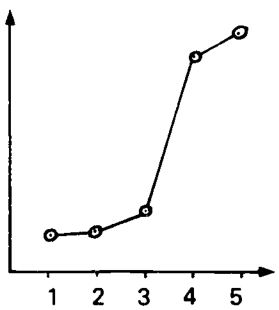
C



B



D



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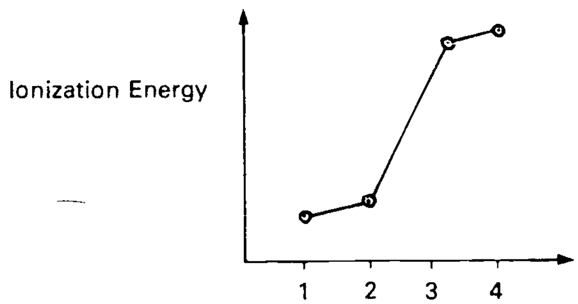
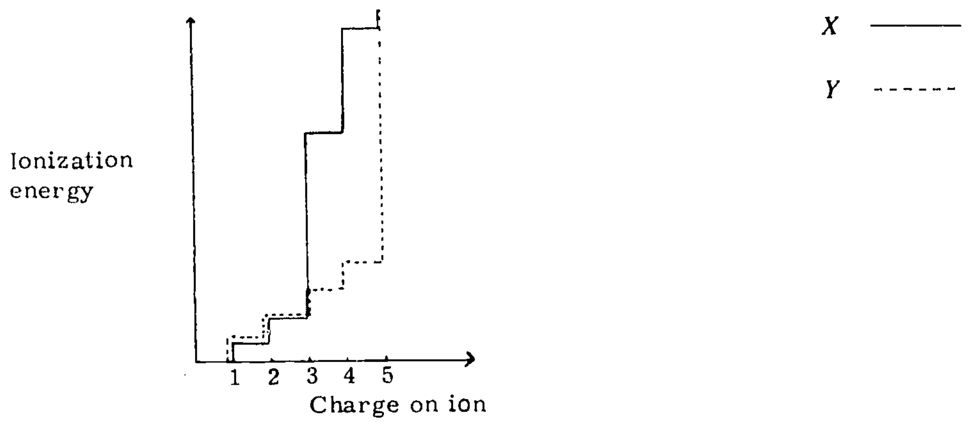
B6c-5 | Below is a plot of the successive ionization energies of an element.
60
B



The element could be

A sodium.
B magnesium.
C aluminium.
D oxygen.

B6c-6 | The graphs below show the variation in ionization energy of two elements, *X* and *Y*, as a function of the charge on an ion.
60
D



For which one of the following conclusions is there **no** evidence in the graphs?

A Element *X* has two valence electrons.
B More energy is required for the reaction $Y \rightarrow Y^{2+} + 2e^-$ than the reaction $X \rightarrow X^{2+} + 2e^-$.
C Element *X* is probably a metal.
D Elements *X* and *Y* are highly electronegative.

B6c-7 | Which of the following atoms or ions would have the greatest ionization energy?
40*
A

A Na^+
B Na
C Mg^+
D F

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C THE PERIODIC TABLE

C1 Historical development

C1-1 | 60 | A

The modern periodic table is the result of studies by many scientists. Early groupings of elements were proposed by

A Dobereiner, Newlands and Mendeleev.
B Mendeleev, Pauli and Boyle.
C Einstein, Mendeleev and Bohr.
D Avogadro, Pauli and Einstein.

C1-2 | 60 | C

In the *original* development of the periodic table, Mendeleev placed the then known elements in an order based on

A known properties and atomic numbers.
B known electronic structures and properties.
C atomic masses and known properties.
D the relative isotopic masses of the various known isotopes.

C1-3 | 40 | D

Which of the following statements about Mendeleev's work on the development of a periodic table is **incorrect?**

A Some elements in his table were placed out of the order of their supposed relative atomic mass.
B Spaces were left in his table for undiscovered elements.
C Properties of elements were found to vary periodically with relative atomic mass.
D Elements were ordered in groups on the basis of their electronic structure.

C2 Organisation of the periodic table

C2-1 | 80 | A

Which one of the following properties of elements is best used as a basis for classifying them into groups in a periodic table?

A electronic structure
B relative atomic mass.
C mass number
D chemical properties

C2-2 | 60 | A

Which of the following configurations represents the outer-shell electron arrangement of the elements of group V?

A s^2p^3 **B** p^5 **C** s^2p^5 **D** $s^2p^3d^5$

C2-3 | 80 | C

Which of the following atomic numbers represents an element in group VI of the periodic table?

A 4 **B** 6 **C** 8 **D** 10

C2-4 | 60 | A

In the electronic ground state, atoms of the element that is in period 4, group V of the periodic table have only

A 5 electrons in the 4th (N) shell.
B 4 electrons in the 5th (O) shell.
C 3 electrons in the 4th (N) shell.
D 3 electrons in the 5th (O) shell.

C2-5 | 70 | A

An atom of an element X has the electronic configuration 2, 8, 18, 6. This element is most probably

A a non-metal, located in group VI of the periodic table.
B a metal, located in group IV of the periodic table.
C a metal that will form an ionic compound with chlorine of empirical formula XCl_2.
D a non-metal which will form a covalent compound with oxygen with the formula X_3O.

C2-6 | 90 | A

Of the elements in the second period, those with atoms which have s-electrons only in their outer electron shells are

A Li and Be. **B** Be and B. **C** N, O and F. **D** Li and Ne.

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C2-7 30* C

If an atom of the element in group IV, period 4 of the periodic table was in its lowest energy state, the number of occupied subshells would be

A 32. **B** 16. **C** 8. **D** 4. **E** 2.

C2-8 50 C

An element has an atomic number of 33. The element will be located in the periodic table in

A group III, period 3.
B group IV, period 5.
C group V, period 4.
D the first transition series.

C2-9 70 A

A neutral atom has the electron configuration
$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^1$.
In the periodic table this element would be located in

A group III, period 4.
B group I, period 4.
C group IV, period 1.
D group IV, period 3.

C2-10 50 B

A neutral atom has the electron configuration
$1s^2 2s^2 2p^6 3s^2 3p^5 4s^1$
Which statement about the atom is **false**?

A It is non-metallic.
B It is in period 4 of the periodic table.
C It must absorb energy to change its configuration to $1s^2 2s^2 2p^6 3s^2 3p^5 4p^1$.
D It is not in its ground (normal) state.

C2-11 30 A

The ion X^{2+} has the electronic configuration

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$.

In the periodic table element X would be located in

A group II.
B group IV.
C group VI.
D group VIII.
E the second transition series.

C2-12 30 D

An atom, in an excited state, has an electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^2 4s^1$. The atom is that of an element from

A group I, period 4.
B group V, period 4.
C group III, period 3.
D group V, period 3.
E group IV, period 1.

C2-13 70 B

The first row transition elements are

A metallic and have partially filled 2d subshells.
B metallic and have partially filled 3d subshells.
C non-metallic and have partially filled 2d subshells.
D non-metallic and have partially filled 3d subshells.

The next three items refer to the following information

Consider the following elements labelled V, W, X, Y and Z. For each element the electronic configuration is listed in the table below.

Element	*Electronic configuration*
V	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 5s^2\ 5p^6\ 6s^2$
W	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^3$
X	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 4f^{14}\ 5s^2\ 5p^6\ 5d^6\ 6s^2$
Y	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 5s^2$
Z	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2$

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C2-14 40 E | Which element belongs in the first transition series?

A *V* B *W* C *X* D *Y* E *Z*

C2-15 30 A | Which element occurs in group II?

A *V* B *W* C *X* D *Y* E *Z*

C2-16 70 B | Which element occurs in group V?

A *V* B *W* C *X* D *Y* E *Z*

C2-17 50 C | The number of orbitals in the f sub-shell is

A 2. B 5. C 7. D 14.

C3 Dependence of properties on electronic structure

C3-1 80 B | A certain element has atoms which each contain 9 electrons. Another element with similar properties has atoms containing

A 11 electrons. B 17 electrons. C 19 electrons. D 27 electrons.

C3-2 90 B | Lithium and sodium have similar physical and chemical properties. This is *best* explained by the fact that both elements

A are metals.
B have the same outer-shell electron configuration.
C have a low relative atomic mass.
D are in period 1 of the periodic table.

C3-3 90 C | Potassium and caesium are both members of group I in the periodic table. A potassium and a caesium atom should have the same

A number of protons in their nuclei.
B total number of electrons around their nuclei.
C characteristic of losing one electron per atom to form an ion.
D nuclear charge.

C3-4 80 C | Selenium (Se) is immediately below sulfur in group VI of the periodic table. It would be expected that selenium is a

A metal and forms a hydride with empirical formula SeH_2.
B non-metal and forms a hydride with empirical formula SeH.
C non-metal and forms a hydride with empirical formula SeH_2.
D metal and forms a hydride with empirical formula SeH.

C3-5 40 B | Selenium atoms have a similar outer-shell electron arrangement to those of oxygen and sulfur. Selenium is likely to

A exist as a gas at room temperature and pressure.
B react with metals to form metal selenides.
C form a hydride which is capable of forming hydrogen bonds.
D exist as isolated atoms in the solid state.

C3-6 40 B | Selenium atoms have the electronic configuration $1s^22s^22p^63s^23p^63d^{10}4s^24p^4$. It would be expected that a major species formed when selenium dioxide reacts with water would be

A $O_2(g)$. B $H_2SeO_3(aq)$. C $Se(OH)_4(aq)$. D $OH^-(aq)$.

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C3-7 70 **C**

Caesium (Cs) is a group I element similar to potassium, and fluorine is a group VII element similar to chlorine. It is likely that the compound caesium fluoride is

A a solid with a low melting point.
B a solid at room temperature, with the empirical formula CsF_2.
C a solid at room temperature, with the empirical formula CsF.
D a pale green gas at room temperature.

C4 Periodic properties of elements

C4-1 50 **B**

Some physical properties of four elements, *L*, *M*, *Q* and *R*, are given in the table below.

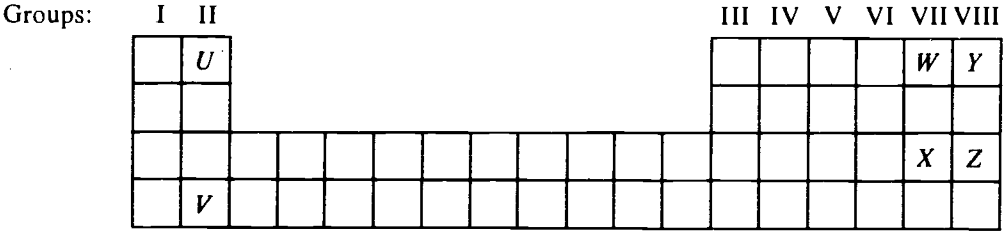
Element	*L*	*M*	*Q*	*R*
MP /°C	−7	63	−189	1083
BP /°C	58	766	−186	2582
Colour at STP	dark red	silvery	colourless	browny-red
Density at STP /g cm^{-3}	3.1	0.86	1.7×10^{-3}	8.9

These elements, in the order *L*, *M*, *Q*, *R*, are from the following groups in the periodic table:

	L	*M*	*Q*	*R*
A	group I	transition elements	group VII	group VIII
B	group VII	group I	group VIII	transition elements
C	group VII	transition elements	group VIII	group I
D	transition elements	group I	group VII	group VIII

The next three items refer to the following information

A section of the periodic table is shown below. The symbols for the elements are fictitious.



C4-2 40 **D**

The element with the highest first ionization energy is

A *U*. **B** *V*. **C** *W*. **D** *Y*. **E** *Z*.

C4-3 80 **C**

The element with the highest electronegativity is

A *U*. **B** *V*. **C** *W*. **D** *X*.

C4-4 90* **A**

Which of the following elements would be the best conductor of electricity?

A *V* **B** *W* **C** *X* **D** *Y*

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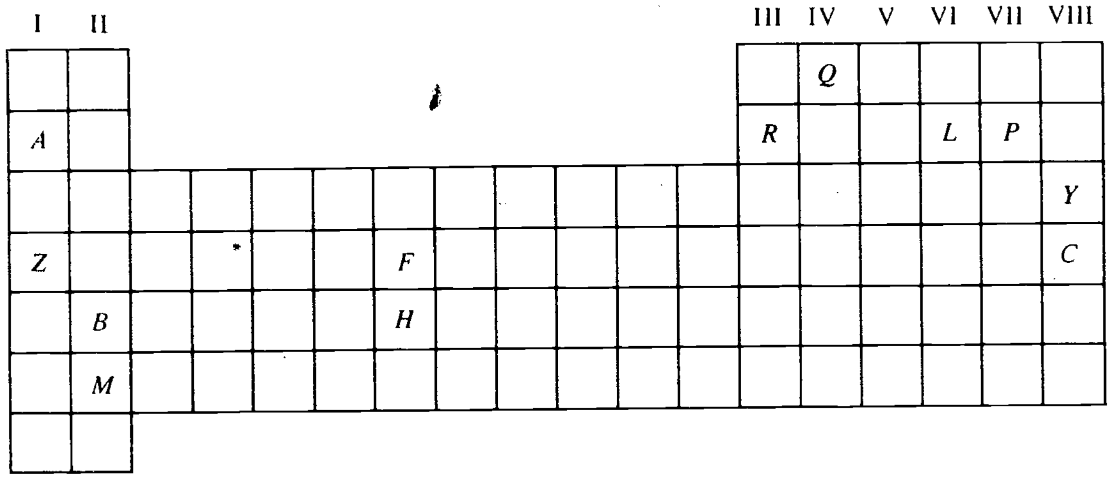
The next four items refer to the following information

A representation of the periodic table is shown below. Certain elements are indicated by letters which are not their usual symbols.



C4-5 50 **A** What amount of atoms of element *B* would react with 1 mol of atoms of element *P* to form a stable compound?

A 0.5 mol **B** 1 mol **C** 2 mol **D** 3 mol

C4-6 40 **A** In which of the following would both of the elements exist as discrete molecules?

A *P* and *L* **B** *Q* and *Y* **C** *R* and *C* **D** *F* and *H* **E** *A* and *B*

C4-7 60 **D** Which one of the elements below most probably has the following properties?

I melting point: 113 °C
II electrical conductivity: poor
III forms a stable hydride in which 2 mol of hydrogen atoms are combined with 1 mol of atoms of the element

A *Z* **B** *B* **C** *P* **D** *L*

C4-8 50 **B** Which of the following compounds is **least** likely to be stable at room conditions?

A RP_3 **B** QL **C** A_2L **D** MP_2

C4a Trends across periods

C4a-1 70 **D** The **least** electronegative element in period 3 of the periodic table is

A Cl. **B** B. **C** Al. **D** Na. **E** K.

The next three items refer to the following information

The elements of the third period of the periodic table are:
Na Mg Al Si P S Cl Ar

C4a-2 80 **A** The element with the lowest first ionization energy is

A Na. **B** Al. **C** Cl. **D** Ar.

C4a-3 90 **D** The element with the highest electronegativity is

A Na. **B** Al. **C** P. **D** Cl.

C4a-4 90* **D** The element which forms the most strongly acidic hydride is

A Na. **B** P. **C** S. **D** Cl.

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The next four items refer to the following information

A section of the periodic table is represented below. The correct symbols have not been used to represent atoms of the elements in period 3.

	I	II	III	IV	V	VI	VII	VIII
Period 2	Li	Be	B	C	N	O	F	Ne
Period 3	*G*	*J*	*L*	*M*	*Q*	*R*	*T*	*X*

C4a-5 80 **A**

The most active metal in period 3 is

A *G*. **B** *J*. **C** *L*. **D** *T*.

C4a-6 80 **C**

The probable formula for a compound of *J* and *T* is

A J_2T. **B** JT. **C** JT_2. **D** J_2T_7.

C4a-7 50 **A**

Of the following, the best reducing agent is

A *J*. **B** *M*. **C** *T*. **D** *X*.

C4a-8 90 **A**

In an oxide of the form Y_2O_3, the element represented by *Y* could be

A *L*. **B** *M*. **C** *R*. **D** *X*.

C4a-9 60* **B**

Which one of the following oxides reacts with water to form the strongest acid?

A Na_2O **B** SO_3 **C** P_4O_{10} **D** SiO_2

C4a-10 60 **D**

Which of the following hydroxy compounds is the most acidic?

A $PO(OH)_3$ **B** $Si(OH)_4$ **C** $Al(OH)_3$ **D** $SO_2(OH)_2$

C4a-11 60* **D**

One of the following hydroxy compounds exhibits *no* significant basic properties in an aqueous solution. Which one?

A $Mg(OH)_2$ **B** $Al(OH)_3$ **C** KOH **D** $PO(OH)_3$

C4a-12 50 **C**

Which of the following hydroxy compounds acts as the **weakest** acid in aqueous solution?

A $PO(OH)_3$ **B** $Si(OH)_4$ **C** $Mg(OH)_2$ **D** $SO_2(OH)_2$

C4a-13 80 **D**

In which case is the bonding present in all three members of the following groups essentially covalent?

A SO_3, P_4O_{10}, Na_2O_2
B Na_2O_2, MgO, Al_2O_3
C Cl_2O_7, Al_2O_3, SO_3
D SiO_2, Cl_2O_7, P_4O_{10}

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D THE MOLE AND CHEMICAL FORMULAE

D1 Relative atomic mass

D1-1 50 C

Which one of the following is a definition of the relative atomic mass of an element?

A the weighted mean of the masses of all possible isotopes of the element on a scale such that naturally occurring carbon has a mass of 12 exactly.

B the weighted mean of the masses of the most abundant isotopes of the element on a scale such that carbon-12 has a mass of 12 g exactly.

C the weighted mean of the isotopic masses of the element on the scale in which an atom of carbon-12 is taken as 12 exactly.

D the weighted mean of the isotopic masses on a scale such that an atom of naturally occurring carbon has a mass of 12 g exactly.

D1-2 50* E

The unit for the quantity 'relative atomic mass' is

A gram. **C** kilogram. **E** none of the above.

B kilogram per mole. **D** gram per mole.

D1-3 40 C

The relative atomic mass of an element is numerically equal to

A the mass of 22.4 dm^3 of the element at STP.

B the sum of the masses of the isotopes.

C the mass of one mole of atoms of the element.

D the total number of protons and neutrons in the atoms of the element.

D1-4 30 A

The relative isotopic mass of the $^{16}_{8}O$ isotope is 15.995 on the scale $^{12}_{6}C = 12$ exactly. If the $^{16}_{8}O$ isotope were taken as the basis for all relative atomic masses (with $^{16}_{8}O = 16$ exactly) then, on this scale, the mass of a $^{12}_{6}C$ isotope would be

A $\frac{16 \times 12}{15.995}$. **C** $\frac{16 \times 15.995}{12}$. **E** $\frac{16}{12 \times 15.995}$.

B $\frac{15.995 \times 12}{16}$. **D** 12.

D1-5 80* D

A carbon-12 atom has a mass of approximately 20.4×10^{-27} kg. The mass of a phosphorus-31 atom would therefore be most nearly

A $31 \times 20.4 \times 10^{-27}$ kg. **C** 31×10^{-27} kg.

B $\frac{31}{12} \times 10^{-27}$ kg. **D** $\frac{31}{12} \times 20.4 \times 10^{-27}$ kg.

D1-6 30 C

If the mass of an atom of ^{12}C is 2.04×10^{-26} kg, the relative atomic mass of an element composed entirely of atoms of mass 6.8×10^{-27} kg would be

A $\frac{2.04 \times 10^{-26}}{6.8 \times 10^{-27}}$. **C** $\frac{6.8 \times 10^{-27} \times 12}{2.04 \times 10^{-26}}$. **E** $\frac{6.8 \times 10^{-27} \times 6.0 \times 10^{23}}{2.04 \times 10^{-26}}$

B $\frac{6.8 \times 10^{-27}}{2.04 \times 10^{-26}}$. **D** $\frac{2.04 \times 10^{-26} \times 12}{6.8 \times 10^{-27}}$.

D1-7 70 B

The element gallium consists of two isotopes, ^{69}Ga and ^{71}Ga. If $\frac{3}{5}$ of the mass of a sample of gallium is present as ^{69}Ga, the relative atomic mass of gallium would be about

A 69.5 **B** 69.8 **C** 70.2 **D** 70.5

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D1-8
90
D

Naturally occurring boron consists of two isotopes with the following approximate percentage abundances.

$^{10}_{5}B$ 20% $^{11}_{5}B$ 80%

The best approximate relative atomic mass of boron is

A 10·0. **B** 10·2. **C** 10·5. **D** 10·8. **E** 11·0.

D1-9
60
C

The element gallium has two isotopes of relative isotopic masses 68·95 and 70·95. Its relative atomic mass is 69·75. The percentage of isotope ^{69}Ga in naturally occurring gallium is

A 40. **B** 50. **C** 60. **D** 70. **E** 80.

D1-10
60
B

Naturally occurring copper consists of two isotopes, ^{63}Cu and ^{65}Cu. If the relative atomic mass of copper is 63.55, which one of the following is the best estimate of the relative abundance of the isotopes in copper?

A 80% ^{63}Cu, 20% ^{65}Cu
B 70% ^{63}Cu, 30% ^{65}Cu
C 50% ^{63}Cu, 50% ^{65}Cu
D 30% ^{63}Cu, 70% ^{65}Cu
E 20% ^{63}Cu, 80% ^{65}Cu

D2 Mass spectra

D2-1
30
A, C, D

Which **one or more** of the following species could be deflected by passage through a magnetic field?

A a proton **B** a neutron **C** an electron **D** an anion

D2-2
80
B

A mass spectrometer is used to determine the

A number of protons and neutrons in a nucleus.
B percentage abundance of isotopes of an element.
C number of atoms in a sample.
D mass of a sample of ^{12}C.

D2-3
60*
D

Which one of the following could **not** be readily determined using a mass spectrometer?

A the number of isotopes in an element
B the relative atomic mass of an element
C the mass number of an isotope
D the atomic number of an element

D2-4
40
A

The relative atomic mass of an element is usually determined by

A analysing the deflection of ions of the element as they pass through a magnetic field.
B measuring the deflection of a beam of alpha particles fired at the element.
C analysing the spectrum obtained when the element is heated and the light emitted is passed through a prism.
D determining the mass of a sample of the element on an accurate balance which has been calibrated using 12 g of carbon-12.

D2-5
70
C

Relative masses of particles are determined with a mass spectrometer by using the fact that

A the velocity of the particles can be accurately determined.
B the force with which the accelerated particles strike the target can be measured.
C the path followed by the particles depends on their charge and their mass.
D larger particles are deflected to a greater extent by a magnetic field.

D2-6
40
B

The species collected by the recorder in a conventional mass spectrometer are

A uncharged.
B positively charged.
C negatively charged.
D both positively and negatively charged.

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D2-7 50 **B**

Which of the following processes is **least** likely to occur in a mass spectrometer?

A formation of cations
B passage of a particle beam through a prism
C separation of particles in a magnetic field
D vaporisation of a sample

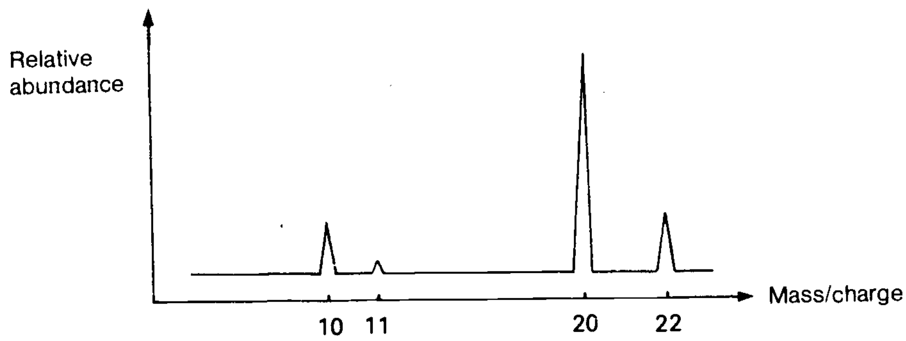
D2-8 50 **C**

The circular path taken by particle *X* in a mass spectrometer has a larger radius than the path taken by particle *Y*. Compared with particle *Y*, particle *X* could

A have the opposite charge and a smaller mass.
B have a greater charge and the same mass.
C have the same charge and a greater mass.
D be uncharged and have a smaller mass.

D2-9 60* **C**

The mass spectrum of element *X* is shown below.



The main isotopes of element *X* are

A ^{10}X, ^{11}X, ^{20}X, ^{22}X.
B ^{10}X, ^{11}X.
C ^{20}X, ^{22}X.
D ^{10}X, ^{20}X.

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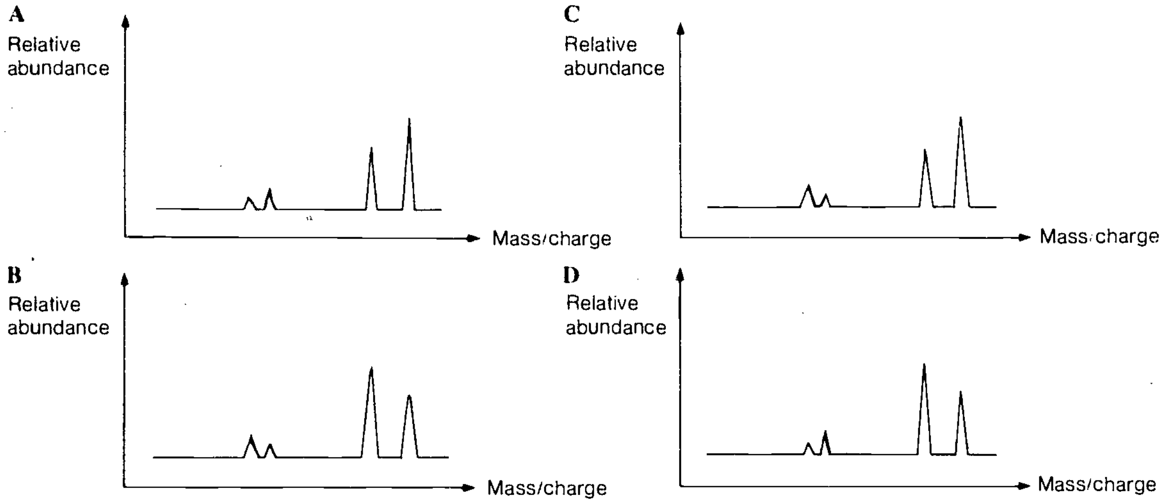
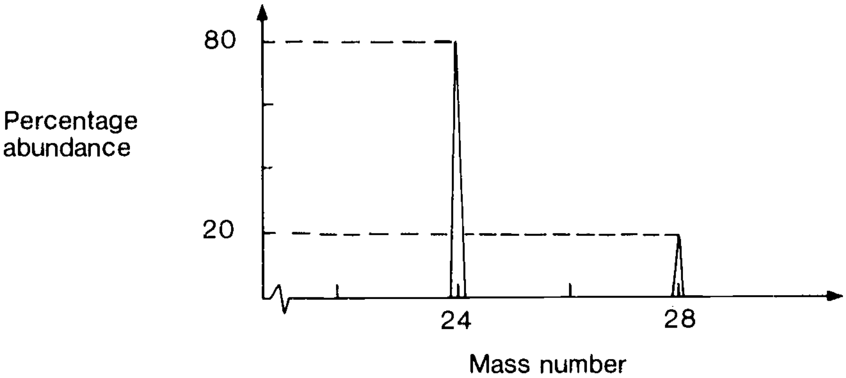
D2-10 The element gallium has two isotopes, ^{69}Ga and ^{71}Ga. The species ^{69}Ga is 60% abundant. A mass spectrum of the element is most likely to resemble
80
B



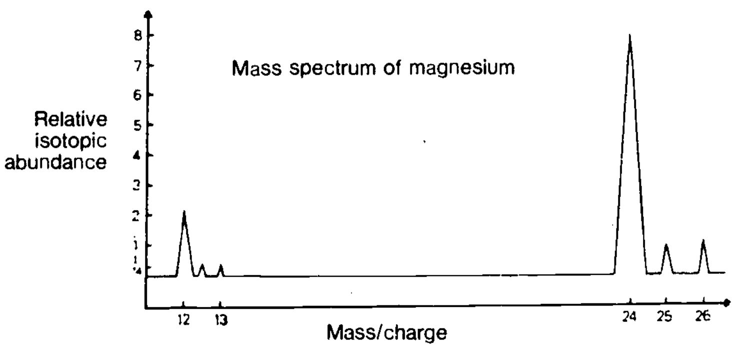
D2-11 The element *X* produces the mass spectrum shown.
70
B



The relative atomic mass of element *X* is approximately

A 24. **B** 25. **C** 26. **D** 27. **E** 28.

The next two items refer to the following diagram



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D2-12 .30* C

The value of the relative atomic mass of magnesium is closest to

A $[(2 \times 12) + (\frac{1}{4} \times 12.5) + (\frac{1}{4} \times 13)]/2\frac{1}{2}$

B $[(8 \times 24) + (1 \times 25) + (1 \times 26)]/3$

C $[(8 \times 24) + (1 \times 25) + (1 \times 26)]/10$

D $[(2 \times 12) + (\frac{1}{4} \times 12.5) + (\frac{1}{4} \times 13) + (8 \times 24) + (1 \times 25) + (1 \times 26)]/12\frac{1}{2}$

D2-13 60* B

The two groups of peaks in the spectrum arise because

A as the magnesium atoms pass through the mass spectrometer some of them are split in half by interaction with the magnetic field, thus producing two separate groups of peaks a factor of two apart.

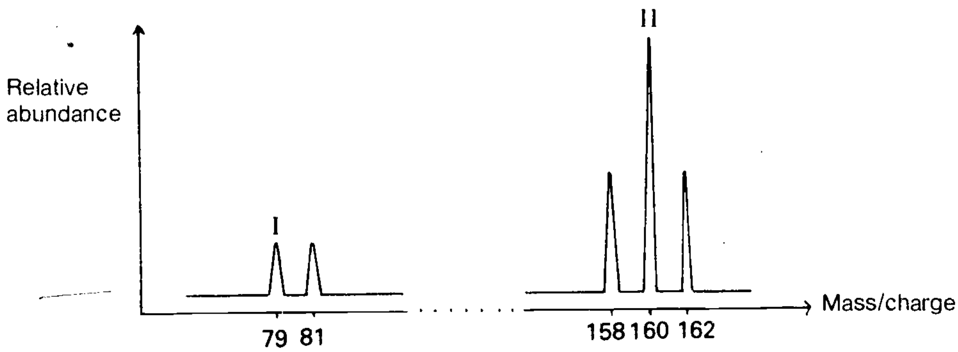
B during the ionization of the magnesium atoms in the mass spectrometer some of the atoms have two electrons removed, while the majority have only one electron removed, thus producing two separate groups of peaks a factor of two apart.

C magnesium exists in the gas phase mainly as Mg_2 molecules; the upper group of peaks is caused by Mg_2^+ ions, and the lower group of peaks by Mg^+ ions.

D as the magnesium passes through the magnetic chamber in the mass spectrometer, a reaction between the magnesium and oxygen from the air occurs; thus the two groups of peaks are caused by Mg atoms and MgO molecules.

The next two items refer to the following information

The mass spectrum of element *X* is represented by the following diagram



D2-14 50* C

Which of the following species is most likely to have produced peak I in the spectrum?

A $^{79}X_2^{2+}$ **B** $^{158}X^{2+}$ **C** $^{79}X^+$ **D** $^{79}X^{2+}$

D2-15 20* D

Which of the following species is most likely to have produced peak II in the spectrum?

A $^{160}X^+$ **B** $^{160}X^{2+}$ **C** $^{80}X_2^+$ **D** $(^{79}X^{81}X)^+$

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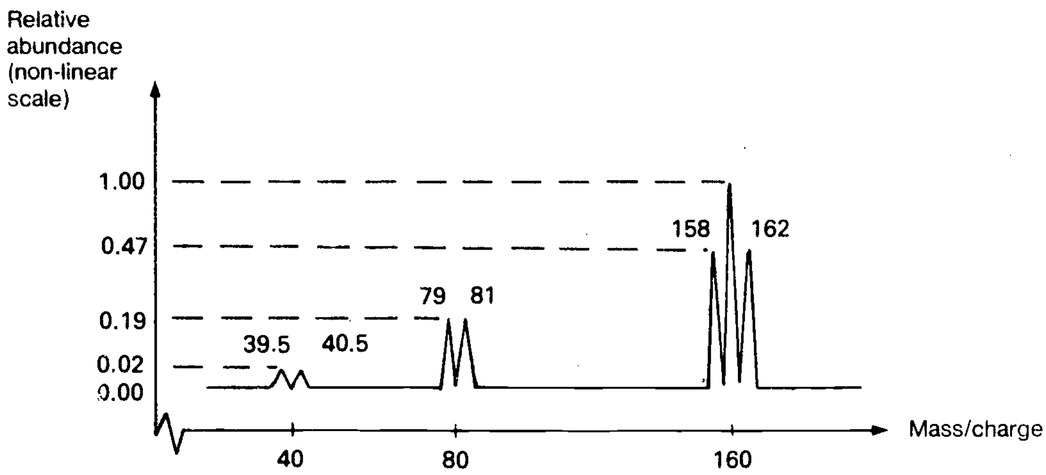
The next two items refer to the following information

The mass spectrum of bromine gas is shown below.



D2-16 The number of isotopes of bromine is
20
A

A 2. **B** 3. **C** 4. **D** 7.

D2-17 The relative atomic mass of bromine is closest to
20
B

A [(162 × 0.47) + (160 × 1.00) + (158 × 0.47)]/1.94

B [(81 × 0.19) + (79 × 0.19)]/0.38

C [(81 × 0.19) + (79 × 0.19) + (40.5 × 0.02) + (39.5 × 0.02)]/0.42

D [(162 × 0.47) + (160 × 1.00) + (158 × 0.47) + (81 × 0.19) + (79 × 0.19) + (40.5 × 0.02) + (39.5 × 0.02)]/2.36

D2-18 If methane (CH_4) were composed of only $^{12}_{6}C$ and $^{1}_{1}H$ atoms, then the peak corresponding to a CH_4^+ ion in a mass spectrum would coincide with that corresponding to the peak produced by a
50
C

A CH_4^{2+} ion. **B** $(^{16}_{8}O)_2^+$ ion. **C** $^{16}_{8}O^+$ ion. **D** CH_3^+ ion. **E** CH_4 molecule.

D2-19 Naturally occurring hydrogen contains the isotopes $^{1}_{1}H$ and $^{2}_{1}H$ while naturally occurring chlorine contains isotopes $^{35}_{17}Cl$ and $^{37}_{17}Cl$. When pure hydrogen chloride is analysed in a mass spectrometer, it would be expected that positive ions would be formed with mass numbers of
80
B

A 18 only.

B 36, 37, 38, 39.

C 72, 78.

D 72, 74, 76, 78.

D2-20 Chlorine (A_r = 35.5) exists naturally in two isotopic forms, ^{35}Cl and ^{37}Cl. A sample of sulfur (A_r = 32.0) also contains two isotopes, ^{32}S and ^{34}S. In the mass spectrum of SCl_2, the mass to charge ratio for the most abundant singly charged species would be closest to
30*
B

A 51.5 **B** 102. **C** 103. **D** 108.

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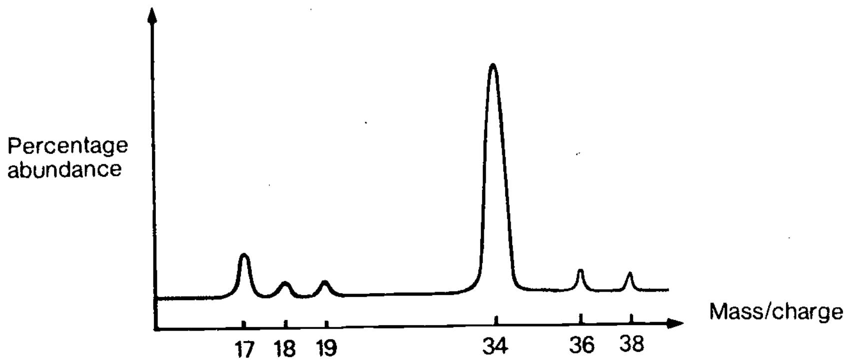
D2-21 30 **A**

A chemist produced the mass spectrum (shown in the diagram) of **one** of the following four substances:

hydrogen peroxide (H_2O_2),
hydrogen sulfide (H_2S),
hydrogen chloride (HCl), or
fluorine (F_2).



Note: The peaks at 18 and 19, 36 and 38 are many times higher than would be the case in an actual mass spectrum of the compound in question. It is impractical in a diagram of this size to draw all the peaks to the same scale.

The percentage abundances of the most common isotopes of the elements concerned are given below:

^{1}H = 100%
^{16}O = 99.8%, ^{18}O = 0.2%
^{19}F = 100%
^{32}S = 95.0%, ^{33}S = 0.74%
^{34}S = 4.2%, ^{36}S = 0.02%
^{35}Cl = 75.4%, ^{37}Cl = 24.6%

The chemist's mass spectrum was most probably that of

A hydrogen peroxide.
B hydrogen sulfide.
C hydrogen chloride.
D fluorine.

D3 The mole

D3-1 70* **D**

The mole is the unit used by chemists to measure the quantity

A relative atomic mass.
B number of atoms.
C concentration of particles.
D amount of substance.

D3-2 90 **C**

The mole is used as a measure of amount of substance in chemistry.
In terms of which one of the following is it defined?

A volume of particles
B size of particles
C number of particles
D concentration of particles

D3-3 70 **D**

One mole of argon atoms resembles one mole of magnesium atoms in that both have the same

A mass.
B volume.
C number of protons.
D number of atoms.

D3-4 90 **C**

The formula of hydrated sodium carbonate (washing soda) is $Na_2CO_3.10H_2O$. What amount of oxygen atoms is there in one mole of $Na_2CO_3.10H_2O$?

A 3 mol **B** 4 mol **C** 13 mol **D** 16 mol

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D4 The Avogadro constant

D4-1 30 **A**

The Avogadro constant is equal to

A the number of molecules in one mole of oxygen gas.
B the number of atoms in 12 g of pure carbon.
C the number of atoms in 16 g of $^{16}_{8}O$.
D the number of elementary charges in one coulomb of charge.

D4-2 70 **A**

The population of Australia is about 1.5×10^7. The Australian population could be expressed as

A 2.5×10^{-17} mol.
B 2.5×10^{-16} mol.
C 4×10^{15} mol.
D 4×10^{16} mol.

D4-3 50 **D**

In one mole of NH_3 molecules there are approximately

A 3×10^{23} atoms.
B 6×10^{23} atoms.
C 1.2×10^{24} atoms.
D 2.4×10^{24} atoms.

D4-4 50 **D**

The mass of one molecule of nitrogen gas is about (given $N_A = 6.0 \times 10^{23}$, A_r N = 14.0)

A $\frac{14.0}{2 \times 6.0 \times 10^{23}}$ g.
B $2 \times 14.0 \times 6.0 \times 10^{-23}$ g.
C $\frac{14.0}{6.0 \times 10^{23}}$ g.
D $\frac{2 \times 14.0}{6.0 \times 10^{23}}$ g.

D4-5 60 **B**

12 g exactly of $^{12}_{6}C$ contains $6{\cdot}0 \times 10^{23}$ atoms of $^{12}_{6}C$. Naturally occurring carbon contains 98·89% $^{12}_{6}C$ and 1·11% $^{13}_{6}C$ by mass. Hence, exactly 12 g of naturally-occurring carbon would contain

A more than $6{\cdot}0 \times 10^{23}$ atoms of $^{12}_{6}C$.
B fewer than $6{\cdot}0 \times 10^{23}$ atoms of $^{12}_{6}C$.
C atoms of $^{12}_{6}C$ and $^{13}_{6}C$ totalling $6{\cdot}0 \times 10^{23}$.
D exactly $6{\cdot}0 \times 10^{23}$ atoms of $^{12}_{6}C$.

D4-6 50 **A**

The formula of the rocket fuel diborane is B_2H_6. Given the value of the Avogadro constant, $N_A = 6.0 \times 10^{23}$, and the relative atomic masses B = 10.8, H = 1.0, which one of the following statements is correct?

A One mole of diborane molecules contains a total of 4.8×10^{24} atoms.
B 0.1 mol of diborane molecules contains 1.08 g of boron.
C The mass of one diborane molecule is $(6.0 \times 10^{23} \div 27.6)$ g.
D 1.5×10^{22} diborane molecules are 0.25 mol of molecules.
E 2.16 g of diborane contains 0.1 mol of diborane molecules.

D5 Molar mass

D5-1 60 **B**

A compound has the molecular formula $A_XB_YC_Z$, where A, B, and C are the symbols of the elements, and X, Y, and Z are the numbers of atoms of each element in a molecule of the substance. The relative atomic masses of the elements are A = p, B = q, C = r. The amount of molecules in 10 g of the substance is

A $\frac{Xp + Yq + Zr}{10}$ mol.
B $\frac{10}{Xp + Yq + Zr}$ mol.
C $10\,(Xp + Yq + Zr)$ mol.
D $10\,(\frac{X}{p} + \frac{Y}{q} + \frac{Z}{r})$ mol.

D5-2 10 **B**

The amount of atoms in 4.4 g of carbon dioxide (M_r = 44) is

A 0.1 mol.
B 0.1×3 mol.
C $0.1 \times 6 \times 10^{23}$ mol.
D $0.1 \times 3 \times 6 \times 10^{23}$ mol.

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D5-3 | Ammonium nitrate, NH_4NO_3, is often added to soil to provide the nitrogen required for plant growth. The amount of nitrogen atoms in 1.0 kg of ammonium nitrate is (given A_r N = 14, M_r NH_4NO_3 = 80)
20*
C

A $\frac{1.0 \times 10^3}{80}$ mol.

B $\frac{2 \times 1.0 \times 10^3}{14}$ mol.

C $\frac{2 \times 1.0 \times 10^3}{80}$ mol.

D $\frac{2 \times 1.0 \times 10^3 \times 14}{80}$ mol.

D5-4 | Given the relative atomic masses: Cu = 63.5, S = 32.1 and 0 = 16.0, the mass of 0.2 mol of anhydrous copper(II) sulfate ($CuSO_4$) is closest to
80
B

A 22 g. B 32 g. C 110 g. D 160 g.

D5-5 | Which of the following lists contains four gaseous samples arranged in order of **increasing** mass (given A_r He = 4.00, N = 14.0, O = 16.0, F = 19.0)?
70
D

A x mol He, $\frac{x}{2}$ mol N_2, $\frac{x}{4}$ mol O_2, $\frac{x}{2}$ mol F_2

B $2y$ mol He, $\frac{y}{4}$ mol N_2, $\frac{y}{4}$ mol O_2, $\frac{y}{2}$ mol F_2

C $3z$ mol He, $\frac{z}{2}$ mol N_2, $\frac{z}{2}$ mol O_2, $\frac{z}{3}$ mol F_2

D v mol He, $\frac{v}{2}$ mol N_2, $\frac{v}{2}$ mol O_2, $\frac{v}{2}$ mol F_2

D5-6 | Which of the following has the greatest mass (given A_r: Hg = 200.6, Fe = 55.8, N = 14, H = 1)?
30
A

A 6×10^{25} molecules of hydrogen gas
B 4 mol of nitrogen molecules
C 1.2×10^{24} atoms of iron
D 120 g of mercury

D5-7 | Which one of the following quantities of nitrogen gas contains the largest number of atoms (given A_r N = 14; Avogadro's constant = 6.02×10^{23})?
80
D

A 140 g
B 14 dm^3 measured at STP
C 14×10^{23} molecules
D 14 mol molecules

D5-8 | Which of the following contains the greatest number of atoms?
30 | (A_r: H = 1, N = 14, O = 16)
B

A 12 g of H_2O
B 17 g of NH_3
C 1.5 mol of nitrogen molecules
D 6×10^{23} oxygen molecules

D5-9 | Which one of the following statements does **not** apply to 1.00 mol of hydrogen molecules (A_r H = 1.01)?
30
A | 1.00 mol of hydrogen molecules

A has a mass of 1.01 g.
B contains 6.02×10^{23} molecules.
C occupies 22.4 dm^3 at STP.
D contains 1.20×10^{24} atoms.

D5-10 | A gardener wishes to provide a nitrogen fertilizer for his soil. Assuming that the following available compounds are equally priced per kilogram and that all the nitrogen present in each is available to plants, which would be the most economical compound for him to purchase?
40*
B

A ammonium chloride (M_r = 53.5)
B ammonium nitrate (M_r = 80)
C ammonium sulfate (M_r = 132)
D potassium nitrate (M_r = 101)

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D5-11 Suppose bulk quantities of the fertilizer ammonium sulfate, $(NH_4)_2SO_4$, cost 135 dollars per tonne. The cost of the fertilizer per gram of nitrogen atoms is (given A_r N = 14; M_r $(NH_4)_2SO_4$ = 132; 1 tonne = 10^6 g)
50
B

A $\frac{135 \times 10^6}{132 \times 14 \times 2}$ dollars.

B $\frac{135 \times 132}{10^6 \times 14 \times 2}$ dollars.

C $\frac{135 \times 132}{10^6 \times 14}$ dollars.

D $\frac{135 \times 14 \times 2 \times 10^6}{132}$ dollars.

D6 Percentage composition

D6-1 Which of the following expressions gives the percentage, by mass, of sulfur in iron(III) sulfide (Fe_2S_3)?
60
B

A $\frac{\text{mass of 1 mol of sulfur atoms}}{\text{mass of 1 mol of } Fe_2S_3} \times \frac{100}{1}$

B $\frac{\text{mass of 3 mol of sulfur atoms}}{\text{mass of 1 mol of } Fe_2S_3} \times \frac{100}{1}$

C $\frac{\text{mass of 1 mol of sulfur atoms}}{\text{mass of 3 mol of } Fe_2S_3} \times \frac{100}{1}$

D $\frac{\text{mass of 3 mol of sulfur atoms}}{\text{mass of 2 mol of iron atoms}} \times \frac{100}{1}$

D6-2 The percentage, by mass, of hydrogen in ammonium dichromate ($(NH_4)_2Cr_2O_7$) is (given A_r N = 14; H = 1; Cr = 52; O = 16)
80
B

A $\frac{1 \times 4 \times 100}{(14 + 4) + (52 \times 2) + (16 \times 7)}$.

B $\frac{1 \times 4 \times 2 \times 100}{2(14 + 4) + (52 \times 2) + (16 \times 7)}$.

C $\frac{1 \times 4 \times 2 \times 100}{(14 + 4) + (52 \times 2) + (16 \times 7)}$.

D $\frac{1 \times 4 \times 100}{2(14 + 4) + (52 \times 2) + (16 \times 7)}$.

D6-3 Nitrogen is excreted from the body in the chemical urea. Urea has the molecular formula NH_2CONH_2. The percentage by mass of nitrogen in 1 mol of urea is (given A_r N = 14; M_r NH_2CONH_2 = 60)
60
C

A $\frac{14}{60} \times 100$.

B $\frac{60}{2 \times 14} \times 100$.

C $\frac{2 \times 14}{60} \times 100$.

D $\frac{2 \times 14}{60} \times 100 \times 6 \times 10^{23}$.

D6-4 x g of an oxide of nitrogen is found to contain y g of nitrogen. The percentage composition by mass of the two elements in the compound is
60
D

A $N = \frac{y}{x - y} \times 100$, $O = \frac{x - y}{x} \times 100$.

B $N = \frac{y}{x} \times 100$, $O = \frac{y}{x + y} \times 100$.

C $N = \frac{y}{x + y} \times 100$, $O = \frac{x - y}{x + y} \times 100$.

D $N = \frac{y}{x} \times 100$, $O = \frac{x - y}{x} \times 100$.

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D6-5 30 C | **A sample of impure limestone had a mass of 10·0 g. When heated strongly, various volatile materials were evolved, but the CO_2 component was isolated and absorbed by passing it through CaO which showed a mass increase of 2·20 g.**

Based on these figures, the carbonate ion (CO_3^{2-}) content in the limestone was (given A_r Ca = 40; C = 12; O = 16)

A 2·2% **B** 22·0% **C** 30·0% **D** 50·0%

D6-6 30 B | A copper ore contains 3.0% by mass of the metal. If the copper is present as Cu_2S, the percentage of Cu_2S in the ore is (given A_r Cu = 63.5; M_r Cu_2S = 159)

A $\frac{3.0 \times 159 \times 100}{63.5}$.

C $\frac{3.0 \times 159}{63.5}$.

B $\frac{3.0 \times 159}{2 \times 63.5}$.

D $\frac{3.0 \times 159 \times 100}{2 \times 63.5}$.

D6-7 90 A | Which of the following nitrogenous fertilizers contains the greatest percentage, by mass, of nitrogen (A_r = 14)?

A urea CON_2H_4 (M_r = 60)
B ammonium sulfate $(NH_4)_2SO_4$ (M_r = 112)
C ammonium nitrate NH_4NO_3 (M_r = 80)
D ammonium phosphate $(NH_4)_3PO_4$ (M_r = 149)

D6-8 40 B | A sample of hydrated copper(II) sulfate, $CuSO_4.5H_2O$, is used to prepare tetrammine copper(II) sulfate, $Cu(NH_3)_4SO_4.H_2O$. The percentage of sulfur by mass in the final product, compared with that of the hydrated copper(II) sulfate, is (given A_r: Cu = 63·5, S = 32, O = 16, N = 14, H = 1)

A the same.
B larger.
C smaller.
D dependent upon the initial mass of reactant.

D7 Law of definite (multiple) proportions

The next two items refer to the following information
Any rock containing a high proportion of iron may be called iron ore. Iron(II) oxide and iron(III) oxide are compounds which are often found in iron ore.

D7-1 70 D | Which one of the following propositions about these substances is correct?

Wherever in the world you find iron deposits, the proportion by mass of

A iron(II) oxide to iron(III) oxide in iron ore will be the same.
B iron to oxygen in every sample of iron oxide will be the same.
C iron to oxygen in iron ore will be the same.
D iron to oxygen in iron(II) oxide will be the same.

D7-2 70* C | A 100 g sample of iron(III) oxide is reduced to iron metal and 70 g of iron is recovered. What is the percentage composition of this compound?
[Relative atomic masses : Fe = 56, O = 16]

A iron 1.25%, oxygen 2%
C iron 70%, oxygen 30%
B iron 56%, oxygen 44%
D iron 56%, oxygen 16%

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D7-3 70* C | 2.5 g of calcium metal combines with 1 g of oxygen to form 3.5 g of calcium oxide. A further sample of calcium was reacted with water. The resulting solution was neutralized with dilute nitric acid, evaporated to dryness and the resulting solid decomposed by heat to form the same oxide of calcium.

The percentage, by mass, of calcium in the second oxide would be approximately

A 29%. **B** 50%. **C** 71%. **D** 98%.

D8 Empirical formulae

D8-1 80 D | Which one of the following lists contains only empirical formulae?

A Na_2O_2, P_4O_{10}, C_6H_{12}, H_2O_2
B ClO_2, N_2O_3, C_6H_{14}, SO_2F_2
C U_3O_8, C_5H_{12}, P_2O_3, N_2O_4
D $CaCO_3$, H_2SO_4, $H_2S_2O_7$, Al_2O_3

D8-2 80 A | Of the following, the only empirical formula is

A P_2O_5. **B** CH_3COOH. **C** Na_2O_2. **D** C_3H_6.

The next two items refer to the following information

A compound used extensively as a solvent for organic compounds has the following percentage composition:

C = 10.04%, H = 0.84%, Cl = 89.12%.
(Relative atomic masses: C = 12, H = 1, Cl = 35.5).

D8-3 60 D | How many hydrogen atoms are there in 100 g of the compound?

A 84 mol **B** 8.4 mol **C** 1 mol **D** 0.84 mol

D8-4 70 A | What is the ratio of the number of atoms of C, H and Cl respectively in this compound?

A $\frac{10.04}{12} : \frac{0.84}{1} : \frac{89.12}{35.5}$

B $10.04 : 0.84 : 89.12$

C $\frac{10.04}{12 + 1 + 35.5} : \frac{1}{12 + 1 + 35.5} : \frac{89.12}{12 + 1 + 35.5}$

D $\frac{12}{10.04} : \frac{1}{0.84} : \frac{35.5}{89.12}$

D8-5 40 B | 31.8 g of element *Y* combines with oxygen to give 47.8 g of a compound. The molar ratio of *Y* to O in this compound is (given A_r *Y* = 63.6, O = 16)

A 1:1. **B** 1:2. **C** 2:1. **D** 2:3. **E** 3:2.

D8-6 60 D | A compound of mass 2.41 g is obtained when 1.77 g of cobalt is reacted completely with oxygen. The empirical formula of the compound is (given A_r Co = 59, O = 16)

A CoO. **B** Co_2O_3. **C** Co_3O_2. **D** Co_3O_4. **E** Co_4O_3.

D8-7 80* C | A carbohydrate which has been detected in interstellar space contains 40.0% carbon and 6.67% of hydrogen, by mass. The empirical formula for the carbohydrate is (given A_r: O = 16, C = 12, H = 1)

A C_2HO_2. **B** CH_2O_2. **C** CH_2O. **D** C_2H_2O.

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D8-8 60 **C** 13.8 g of a rocket fuel containing only boron and hydrogen is burnt in air and the water produced is found to have a mass of 27.0 g. The empirical formula of the compound is (given A_r: O = 16.0, B = 10.8, H = 1)

A BH. **B** BH_2. **C** BH_3. **D** BH_4.

D8-9 60 **B** Gypsum is a mineral composed of hydrated calcium sulfate. 8.6 g of gypsum was strongly heated to leave a residue of anhydrous calcium sulfate of mass 6.8 g. The formula of gypsum is (given M_r $CaSO_4$ = 136, H_2O = 18)

A $CaSO_4.H_2O$
B $CaSO_4.2H_2O$
C $CaSO_4.5H_2O$
D $CaSO_4.6H_2O$

D8-10 50 **B** 3.04 g of a metal oxide, M_2O_3, was treated with aluminium powder to yield 2.08 g of the metal. If the relative atomic mass of oxygen is 16, the relative atomic mass of the metal is

A 26. **B** 52. **C** 104. **D** 208.

D8-11 50 **B** An oxide of formula XO_2 was extracted from a sample of beach sand. If the oxide contains 40% by mass oxygen (A_r = 16.0), the relative atomic mass of *X* is

A 24. **B** 48. **C** 60. **D** 80.

D8-12 30 **D** A gaseous compound of nitrogen (A_r = 14) and oxygen (A_r = 16) is shown by experiment to have a relative molecular mass in the range of 50 to 100, and to contain a little over 30% nitrogen by mass.

The number of atoms of oxygen per molecule of the compound is

A 1. **B** 2. **C** 3. **D** 4. **E** 5.

D9 Molecular formulae

D9-1 70 **C** The molecular formula of a compound is ZX_3 and provides the information that

A in any sample of the compound the mass of *X* is three times the mass of *Z*.
B the ratio of *Z* to *X* in any sample of the compound is 3 : 1.
C each molecule of this compound contains one atom of element *Z* and three atoms of element *X*.
D the mass of element *Z* is greater than the mass of element *X*.

(There may be more than one correct answer to this question).

D9-2 90 **C** TNB is an organic compound which is more explosive than, but chemically similar to, TNT. TNB has an empirical formula C_2HNO_2. Its relative molecular mass is 213. The molecular formula of TNB is (given A_r C = 12, H = 1, N = 14, O = 16)

A C_2HNO_2.
B $C_4H_2N_2O_4$.
C $C_6H_3N_3O_6$.
D $C_8H_4N_4O_8$.

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D9-3 70 **C**

A compound of nitrogen and oxygen has the empirical formula N_wO_x and the molecular formula N_yO_z. The molecular formula mass equals the empirical formula mass multiplied by n, where n is a positive integer. The value of n can be determined from one of the following expressions. Which one (given A_r O = 16, N = 14)?

A $n = \frac{14\,(y + z)}{16\,(w + x)}$

B $n = \frac{14\,(y + z)}{16\,(x + z)}$

C $n = \frac{14y + 16z}{14w + 16x}$

D $n = \frac{14w + 16x}{14y + 16z}$

D9-4 20 **A, B, D**

A plant extract, E, is a solid compound containing only the elements carbon (C), hydrogen (H) and oxygen (O).

Which **one or more** of the following experimental determinations would provide the minimum amount of information necessary to determine the molecular formula of E?

A percentage by mass of C in E

B percentage by mass of H in E

C volume of E at STP

D relative molecular mass of E

E mass of E

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E MOLECULAR COMPOUNDS

E1 Electronic structure and formulae

E1-1 40 **D**
Element P has 3 outer-shell electrons and element Q has 6 outer-shell electrons. A compound formed from these elements is most likely to have the formula

A P_2Q. **B** PQ_2. **C** P_3Q. **D** P_2Q_3.

E1-2 40 **D**
A neutral atom in an excited state has an electronic configuration of $1s^22s^22p^63s^23p^34s^2$. If the element concerned, X, formed a hydride, the compound would most likely be

A ionic, of formula XH_2.
B ionic, of formula XH.
C covalent, of formula XH_2.
D covalent, of formula XH.

E1-3 20 **C**
An element X forms molecules of formula X_3N. The electronic configuration of neutral atoms of element X could be

A $1s^22s^22p^1$. **B** $1s^22s^22p^63s^1$. **C** $1s^22s^22p^5$. **D** $1s^22s^22p^3$.

E1-4 50* **A**
Atoms of element X have an outer-shell electron configuration of s^2p^3.
Atoms of element Y have an outer-shell electron configuration of s^2p^5.
One compound formed from X and Y is likely to have the formula

A XY_3. **B** XY. **C** X_5Y_3. **D** X_3Y_5.

E1-5 80 **B**
The only compound of elements X and Y has the formula X_3Y_2, and the acid formed from Y has the formula H_3Y.

Which one of the following is the most likely formula of a compound of X and hydrogen?

A X_2H_3 **B** XH_2 **C** X_2H **D** X_3H_2

E2 Common molecular compounds

E2-1 50* **B**
HF exists as a crystalline molecular solid below 19 °C. The bonds that hold the hydrogen and fluorine atoms together **within** the HF molecules are best described as

A ionic bonds.
B covalent bonds.
C hydrogen bonds.
D dispersion forces plus hydrogen bonds.

E2-2 40 **E**
One of the following substances does **not** have strong bonds extending throughout the crystal. Which one?

A Ca(s) **B** KNO_3(s) **C** SiC(s) **D** LiBr(s) **E** NH_3(s)

E2-3 60 **B, D**
Which **one or more** of the following pairs of elements react(s) to form a compound containing covalent bonds?

A potassium and fluorine
B hydrogen and oxygen
C oxygen and calcium
D carbon and chlorine

E2-4 10 **C, D**
Which **one or more** of the substances below exist(s) as molecular crystals in the solid state?

A potassium chloride **B** sodium **C** sulfur **D** ice

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E3 Electronic structure of molecules

E3-1 70 **B** Phosphorus is in group V of the periodic table. The bonding in a P_2H_4 molecule would be best represented by the electron dot formula

A
```
 H  H
:P: :P:
 H  H
```
B
```
 H H
:P:P:
 H H
```
C
```
 H H
·P:P·
 H H
```
D
```
H  H
P: :P
H  H
```

E3-2 80 **B** Which one of the following electron dot diagrams best represents the bonding in the nitrogen molecule?

A N:N **B** :N:::N: **C** N::N **D** :N:N:

E3-3 50 **C** Which one of the following electron dot formulae is **incorrect**?

A :N:::N:

B
```
:O:H
 H
```
C
```
H:C:H
  H
```
D :F:F:

E3-4 40 **C** Which of the following electron dot representations of chemical bonding is (are) **incorrect**?

I
```
  H
H:C:Cl:
  H
```
CH_3Cl — chloromethane

II
```
[   H   ]+
[ H:N:H ]    [:S:]2-
[   H   ]2
```
$(NH_4)_2S$ — ammonium sulfide

III
```
H H
N:N
H H
```
N_2H_4 — hydrazine

IV :O:H:H:O: — H_2O_2 — hydrogen peroxide

A IV only **B** II only **C** III and IV **D** I and III **E** II and IV

E3-5 40 **C** s^2p^1 is the electronic configuration in the outer shell of element Z. Which one of the following covalent ions or molecules is most likely to be stable?

A ZCl_5 **B** ZCl_4 **C** ZCl_4^- **D** ZCl_2O

E3-6 50 **C** The number of lone pairs in a molecule of chlorine is

A 3. **B** 4. **C** 6. **D** 7.

E3-7 70 **D** The diatomic molecule in the following list which contains the **greatest** number of *non-bonding outer-shell* electron pairs is

A H_2. **B** N_2. **C** O_2. **D** F_2.

E3-8 70 **B** The electronic configuration of F is $1s^22s^22p^5$. In the F_2 molecule the total number of *inner-shell* electrons is

A 2. **B** 4. **C** 6. **D** 8.

E3-9 70 **C** The number of bonding electron pairs in a molecule of nitrogen is

A 1. **B** 2. **C** 3. **D** 4. **E** 6.

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E3-10
30
B

The number of non-bonding outer-shell electrons in a molecule of nitrogen is

A 2. **B** 4. **C** 6. **D** 10.

E3-11
70
C

An element *E*, electronic configuration 2, 6, forms a compound with hydrogen. How many **pairs** of non-bonding electrons are there in the valence shell of *E* in a molecule of the compound?

A 0 **B** 1 **C** 2 **D** 3 **E** 4

E3-12
90
B

The number of bonding electrons in a molecule of carbon dioxide is

A 4. **B** 8. **C** 12. **D** 16.

E4 Molecular shapes

E4-1
60
D

The shapes of many simple molecules can be predicted by the electron pair repulsion hypothesis. The electron pair repulsion hypothesis states that

A orbitals in the outer shell of an atom stay as far away from each other as possible.
B bonding electron pairs stay as far away from each other as possible.
C non-bonding electron pairs stay as far away from each other as possible.
D electron pairs in the outer shell of an atom stay as far away from each other as possible.

E4-2
60
A

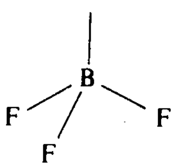
On the basis of the electron pair repulsion hypothesis, which one of the following species would be expected to be linear?

A BeH_2 **B** OH_2 **C** OF_2 **D** NH_2^-

E4-3
80
B

The molecule BF_3 is best represented by the structure

A



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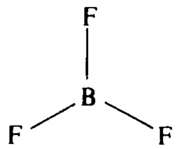

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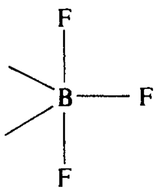

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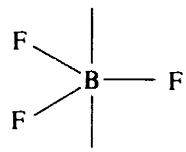


E4-4
70*
C

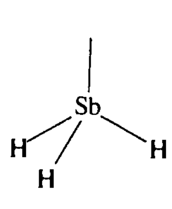
The element boron forms 3 single covalent bonds with another element *X* in the compound BX_3. The bond angle *XBX* in the compound BX_3 is likely to be closest to

A 90°. **B** 109° 28′. **C** 120°. **D** 180°.

E4-5
60*
A

Antimony, symbol Sb, has the same outer-shell electron configuration as phosphorus. The molecule SbH_3 is best represented by the structure

A



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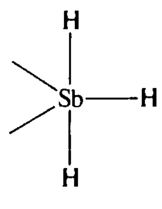
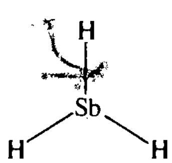
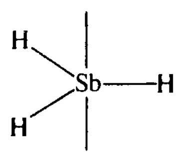


B



D



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E4-6
60*
B

Atoms of element A have five electrons in their outer shells. In the compound AF_3 the FAF bond angle is likely to be closest to

A 90°. **B** 109° 28′. **C** 120°. **D** 150°.

E4-7
20*
A

Many unusual and unfamiliar species can be detected in flames. Thus, in the flame produced when methane burns in oxygen, the very reactive and short-lived species CH_3^+ and CH_2 have been detected. On the basis of the electron pair repulsion hypothesis, the expected shapes of these two species would be

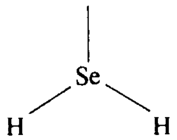
A CH_3^+ triangular planar; CH_2 V-shaped.
B CH_3^+ triangular planar; CH_2 linear.
C CH_3^+ pyramidal; CH_2 V-shaped.
D CH_3^+ pyramidal; CH_2 linear.

E4-8
40
C

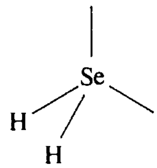
The element selenium is in group VI of the periodic table. The molecule H_2Se is best represented by the structure

A H —— Se —— H

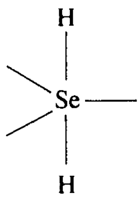
B



C



D



E4-9
30
D

On the basis of the electron pair repulsion hypothesis, which one of the following species would **not** be expected to be tetrahedral?

A SiF_4 **B** BF_4^- **C** BeF_4^{2-} **D** SF_4

E4-10
20*
C

The shape of a molecule is determined by the relative positions of the atomic nuclei, which are in turn determined by the arrangement of outer-shell electron pairs around these nuclei.

In which one of the following species does the arrangement of outer-shell electron pairs around the underlined atom differ from all the others?

A $\underline{N}H_4^+$. **B** $H\underline{F}$. **C** $\underline{Cl}F_3$. **D** $\underline{C}Cl_4$.

E4-11
30*
B

A carbon-carbon single covalent bond is 1.54×10^{-8} cm long. The shortest distance between end carbon atoms in a propane molecule, C_3H_8, would be expected to be

A less than 1.54×10^{-8} cm.
B between 1.54×10^{-8} cm and 3.08×10^{-8} cm.
C 3.08×10^{-8} cm.
D between 3.08×10^{-8} cm and 4.62×10^{-8} cm.
E 4.62×10^{-8} cm.

E4-12
60*
D

A theory used to predict the shapes of molecules (associated with the names of Gillespie and Nyholm) is based on the repulsion effect of electron charge clouds. One feature of the theory is that

A the shape of a molecule is identical with the arrangement of charge clouds containing electron pairs.
B repulsion between lone pairs of electrons is less than that between a bonding and a non-bonding pair.
C outer-shell and inner-shell electrons contribute substantially to molecular shape.
D repulsion between two bonding pairs of electrons is less than that between two non-bonding pairs.

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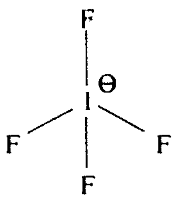
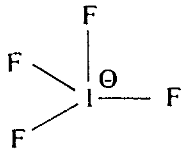
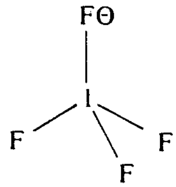
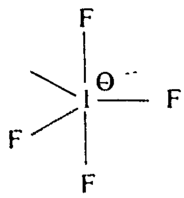
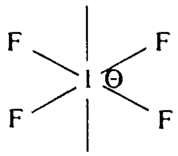
E4-13 10 **D** Which one of the following best represents the arrangement of atoms in the IF_4^- ion?

A 

C 

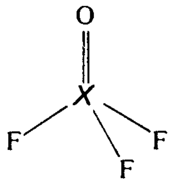
E 

B 

D 

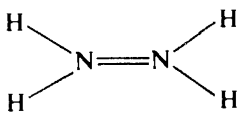
E4-14 70 **B** An atom *X* is involved in a molecule of the structure shown.

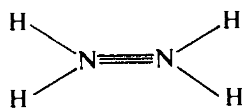
Atom *X* is most likely to be

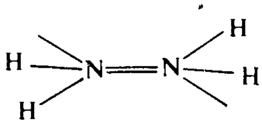


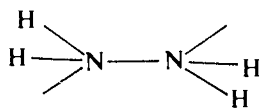
A silicon. **B** phosphorus. **C** sulfur. **D** nitrogen.

E4-15 40 **D** The molecule N_2H_4 is best represented by the structure

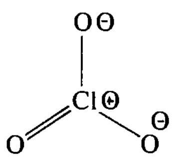
A 

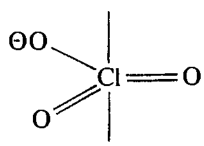
C 

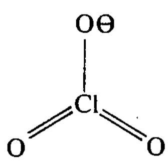
B 

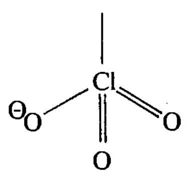
D 

E4-16 30* **D** Which one of the following best represents the structure of the chlorate ion?

A 

C 

B 

D 

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ERIC

E4-17 70* A

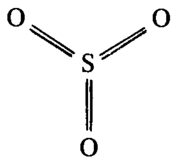
The arrangement of atoms about the central atom in the ClO_4^- ion is best described as forming a

A tetrahedron.
B trigonal bipyramid.
C triangular plane.
D trigonal pyramid.

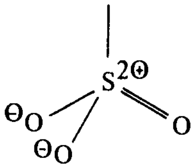
E4-18 90 A

Which one of the following best represents the valence structure of a sulfur trioxide molecule?

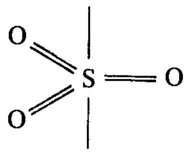
A



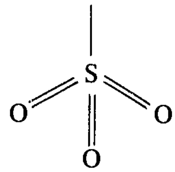
B



C



D



E4-19 60 A

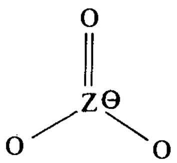
The shape of a sulfur trioxide molecule is

A triangular planar.
B tetrahedral.
C V shaped
D trigonal pyramidal.

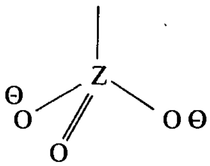
E4-20 20 B

Which of the following oxy-anions would most likely be formed by an element, Z, with the electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4$?

A



B



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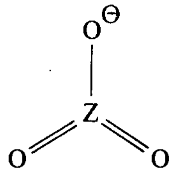
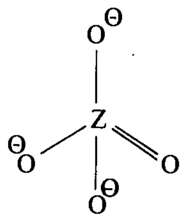


D



E5 Bond dissociation energy

E5-1 30 D

The bond dissociation energy of hydrogen bromide, HBr, is 366 kJ mol^{-1}.

This means that 366 kJ of energy would

A be released when a mole of gaseous HBr molecules dissociates to give hydrogen ions and bromide ions.
B need to be supplied in order to dissociate a mole of gaseous HBr molecules into hydrogen ions and bromide ions.
C be released when a mole of gaseous HBr molecules dissociates to give hydrogen atoms and bromine atoms.
D need to be supplied in order to dissociate a mole of gaseous HBr molecules into hydrogen atoms and bromine atoms.

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E5-2 40* A

Which one of the following sets of molecules is arranged in order of increasing bond dissociation energy?

A Cl_2, O_2, N_2
B N_2, Cl_2, O_2
C N_2, O_2, Cl_2
D O_2, Cl_2, N_2

E5-3 30* C

Which of the following diatomic molecules has the greatest bond strength?

A HF B HBr C N_2 D F_2

E6 Electronegativity

E6-1 80* C

Which of the following statements about electronegativity is the most accurate?

The electronegativity of an atom is a measure of

A the energy released when an electron is added to the atom in the gas phase.
B the energy required to remove an electron from the atom in the gas phase.
C the electron-attracting power of the atom.
D the fractional negative charge on the atom in a molecule.

E6-2 40 D

Which of the following elements is the **most** electronegative?

A calcium B barium C potassium D magnesium

E6-3 70 B

Which of the following elements is **least** electronegative?

A Li B K C F D Br

E6-4 90* B

Which of the following statements about electronegativity is the most accurate?

In relation to the periodic table the electronegativities of elements

A increase from left to right across a period and increase down a group.
B increase from left to right across a period and decrease down a group.
C decrease from left to right across a period and increase down a group.
D decrease from left to right across a period and decrease down a group.

E6-5 70 A

In which of the following are the elements arranged in order of **increasing** electronegativity; the lowest first?

A Si P S Cl B Cl S P Si C Cl Si P S D Si S P Cl

E6-6 90 B

Of the following pairs of elements, which has the largest electronegativity difference?

A Li and B B Be and F C B and O D C and N

The next two items refer to the following information

Elements *W*, *X*, *Y* and *Z* have the electronic configurations listed below.

W $1s^2 2s^1$
X $1s^2 2s^2 2p^6 3s^2 3p^3$
Y $1s^2 2s^2 2p^6 3s^2 3p^5$
Z $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^1$

E6-7 50 D

Which of the elements is most likely to form an ion of charge +3?

A *W* B *X* C *Y* D *Z*

E6-8 60 C

Which of the elements is most electronegative?

A *W* B *X* C *Y* D *Z*

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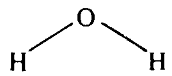
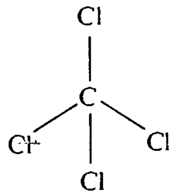
E7 Bond polarity

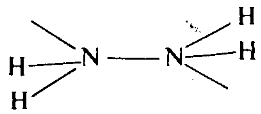
E7-1
50
D

Which one of the following molecules contains a bond which is non-polar?

A 

B H—Cl

C 

D 

E7-2
60
C

Which one of the following molecules is non-polar?

A CH_3Br
B NH_3
C CCl_4
D CH_3CH_2OH

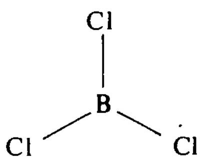
E7-3
70
A,C

Which **one or more** of the following solvents is(are) non-polar?

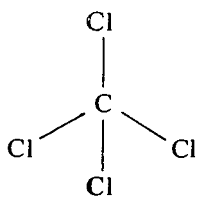
A benzene (C_6H_6)
B ethanol (CH_3CH_2OH)
C n-hexane (C_6H_{14})
D water (H_2O)

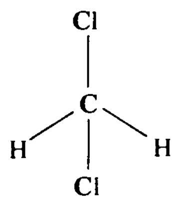
E7-4
60
D

One of the following molecules is polar. Which one?

A 

B O═C═O

C 

D 

E7-5
70
A

In which one of the following molecules does the covalent bond have the greatest polarity, i.e. the greatest departure from equal sharing of electrons?

A HF **B** NH_3 **C** CH **D** H_2O

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E8 Melting temperature and intermolecular bond strength

E8-1 80 **B**

When sugar ($C_{12}H_{22}O_{11}$) is heated, it first melts and then on further heating is observed to char or blacken. This charring is due to formation of carbon. The two processes (melting and charring) can be related to the forces in the sugar crystals as follows:

A Both the melting and charring are due to the thermal energy overcoming the forces *within* the molecules.

B The melting is due to thermal energy overcoming the forces *between* molecules; the charring is due to thermal energy overcoming the forces *within* the molecules.

C The melting is due to thermal energy overcoming the forces *within* the molecules; the charring is due to thermal energy overcoming the forces *between* the molecules.

D Both the melting and charring are due to the thermal energy overcoming the forces *between* the molecules.

E8-2 40 **D**

The melting temperatures of some common molecular substances are given below:

Substance	*Melting Temperature /°C*
Br_2	−7
Cl_2	−101
N_2O_4	−10
HBr	−85

Of the four substances listed, the one in which forces *within* the molecules are *least*

A is Br_2.

B is Cl_2.

C is HBr.

D cannot be determined from the melting temperature.

E8-3 60 **A**

Arsine (AsH_3) melts at 137.5 K and boils at 185.6 K. These values are a measure of

A the strength of the bond between arsine molecules.

B the strength of the bond between arsenic and hydrogen atoms in arsine molecules.

C the stability of the arsine molecules.

D the strength of the bond between hydrogen atoms on neighbouring arsine molecules.

E8-4 70 **C**

Which one of the following substances is likely to have the lowest melting temperature?

A magnesium **B** calcium bromide **C** hydrogen chloride **D** silicon dioxide

E9 Dispersion forces

E9-1 70 **D**

The element argon exists as a crystalline solid at temperatures below −190 °C. The bonding that holds the argon atoms in the lattice is best described as

A ionic bonding. **B** covalent bonding. **C** hydrogen bonding. **D** dispersion forces.

E9-2 50 **B**

Of the following substances, the one with only dispersion forces between molecules in the liquid state is

A sodium chloride. **B** methane. **C** water. **D** magnesium. **E** ammonia.

E9-3 40 **A, C**

Which **one or more** of the following bond-types would be present in a sample of **solid** methane (CH_4)?

A covalent **B** ionic **C** dispersion **D** hydrogen

E9-4 20 **B**

The strength of dispersion forces is a major influence on the melting temperature of

A diamond. **B** chlorine. **C** sodium. **D** ammonium sulfide.

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E9-5 80 C

Which of the following statements best describes the structure of solid carbon dioxide?

A It is an array of positive carbon ions and negative oxide ions.

B Each carbon atom is joined by strong covalent bonds to four oxygen atoms to give an array of many thousands of atoms.

C Molecules, each containing one carbon atom covalently bonded to two oxygen atoms, are held together by weak intermolecular forces.

D Carbon atoms and covalently bonded oxygen molecules are held together by weak intermolecular forces.

E Carbon and oxygen nuclei are held in a lattice by a 'sea of electrons'.

E9-6 30* B

When naphthalene melts, the dispersion forces between the molecules are

A increased slightly, but not enough to overcome the increased thermal motion.

B about as strong as in the solid, but thermal motion disrupts the ordered arrangement of molecules.

C much less than at lower temperatures.

D non-existent.

E9-7 50 A

The boiling temperatures of HCl, HBr and HI are −85, −67 and −35 °C, respectively. Which of the following best explains these different boiling temperatures?

A The strength of dispersion forces increases as the number of electrons present in a molecule increases.

B The strength of hydrogen bonds increases as the number of electrons present in a molecule increases.

C The molecules become more polar as the number of electrons present increases.

D The strength of hydrogen bonds decreases as the number of electrons present in a molecule increases.

E9-8 40 B

Bromine has a higher boiling point than chlorine. Essentially this is because

A bromine molecules are heavier than chlorine molecules and thus they need more kinetic energy to overcome gravitational forces.

B bromine molecules have more electrons and therefore the dispersion forces between them are greater than in chlorine.

C the covalent bond holding bromine atoms together is stronger than the bond in chlorine.

D bromine molecules are slightly more polar than chlorine and therefore the forces between them are greater than in chlorine.

E10 Permanent dipoles, Hydrogen bonds

E10-1 50 B

In which one of the following would permanent dipoles be most influential in holding the molecules together in the solid state?

A carbon tetrafluoride

B hydrogen bromide

C carbon disulfide

D boron trifluoride

E10-2 40 A

Below 19 °C HF exists as a crystalline molecular solid. The bonding that holds the HF molecules into the lattice is best described as

A dispersion forces plus hydrogen bonding.

B ionic bonding plus hydrogen bonding.

C ionic bonding only.

D hydrogen bonding only.

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E10-3 50 C

Water exists as discrete H_2O molecules with the two hydrogen atoms each covalently bonded to oxygen. Below 0 °C at atmospheric pressure, water exists as a crystalline solid, ice, in which the individual H_2O molecules are held in an open network lattice.

The bonding that holds the water molecules together in the ice lattice is best described as being due to

A dispersion forces only.
B hydrogen bonding only.
C dispersion forces plus hydrogen bonding.
D ionic bonding.
E ionic bonding plus hydrogen bonding.

E10-4 20 B

Which **one or more** of the following compounds will have a melting point which is significantly influenced by hydrogen bonding?

A F_2O
B $CH_3CH_2NH_2$
C CH_3F
D H_2S
E PH_3

E10-5 50 B

Ammonia, NH_3, has a considerably higher boiling temperature than phosphine, PH_3. This fact is best explained as being due to

A stronger dispersion forces between NH_3 molecules than between PH_3 molecules.
B stronger dipolar bonding forces between NH_3 molecules than between PH_3 molecules.
C N−H covalent bonds being stronger than P−H covalent bonds.
D N−H covalent bonds being weaker than P−H covalent bonds.

E10-6 50 A

The abnormally high boiling temperature of ammonia compared with that of the other hydrides of the group V elements is due to

A the presence of hydrogen bonds between ammonia molecules but not between the molecules of the other hydrides.
B the presence of stronger bonds within the ammonia molecule than those within the other molecules.
C the higher first ionization energy of the nitrogen atom in the ammonia molecule.
D the much greater solubility of ammonia in water.

E11 Properties of molecular compounds

E11-1 40 B

A substance with a boiling temperature of −85 °C does not conduct electricity in the solid or liquid state, but conducts electricity when dissolved in water.

Of the following, the structure of the substance in the solid state is probably

A a covalent network lattice.
B a molecular crystal.
C an ionic network lattice.
D an ionic layer lattice.

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F INFINITE ARRAYS

F1 Covalent network solids

F1-1 50 C

A network lattice with covalent bonds is often formed by atoms

- A of low electronegativity and a small number of valence electrons.
- B of moderate electronegativity and six or seven valence electrons.
- C of moderate electronegativity with between three and five valence electrons.
- D of high electronegativity and a large number of valence electrons.

F1-2 80 A

At ordinary temperatures and atmospheric pressure, carbon can exist in a solid crystalline form known as diamond. Carbon atoms in diamond are held together mainly by

- A covalent bonding.
- B ionic bonding.
- C hydrogen bonding.
- D dispersion forces.

F1-3 40 B

Solid carbon dioxide is more readily vaporized than diamond, although the strength of carbon-to-carbon bonds is of the same order of magnitude as that of carbon-to-oxygen bonds. The best explanation of this fact is that

- A solid carbon dioxide forms a layer lattice whereas diamond forms a three-dimensional network lattice.
- B when solid carbon dioxide is vaporized only weak bonding forces between CO_2 molecules are disrupted.
- C dispersion forces between diamond molecules are stronger than those between CO_2 molecules.
- D double bonds occur between carbon and oxygen atoms whereas only single bonds occur between atoms in diamond.

F1-4 60 A

In which one of the following substances does strong covalent bonds **not** extend throughout the crystal?

- A $CO_2(s)$
- B C (diamond)
- C Si(s)
- D $SiO_2(s)$

F1-5 60 A

Silicon carbide (SiC) has a structure identical with that of diamond, with silicon and carbon atoms alternating throughout the lattice. Thus in solid silicon carbide

- A each carbon atom is surrounded by four adjacent silicon atoms in a tetrahedral arrangement.
- B there are molecules each of which contains one silicon atom surrounded by four carbon atoms.
- C silicon and carbon atoms are packed into a cubic lattice with six silicon atoms around each carbon atom and six carbon atoms around each silicon atom.
- D silicon and carbon atoms are closely packed with the atoms fitting together as densely as possible.

F1-6 50 B

Silicon dioxide occurs widely in the earth's crust in the form of the mineral quartz.
The structure and bonding of solid silicon dioxide (SiO_2) at room temperature is best described as

- A a network lattice of Si^{2+} cations and O^{2-} anions held together by electrostatic forces.
- B a network lattice of Si atoms and O atoms held together by strong covalent bonds.
- C a layer lattice consisting of hexagonal sheets of atoms covalently bonded together. The sheets are held together by dispersion forces.
- D a lattice of SiO_2 molecules, with a strong covalent bond between the atoms. The molecules are held together by strong dispersion forces.

F1-7 60 C

Silicon dioxide melts at 1700 °C, whereas carbon dioxide is a gas at room temperature. This difference mainly arises because

- A carbon-oxygen bonds are weaker than silicon-oxygen bonds.
- B dispersion forces between SiO_2 molecules are stronger than those between CO_2 molecules.
- C solid silicon dioxide is a covalent network lattice whereas solid carbon dioxide is a molecular crystal.
- D electrostatic attraction between ions in solid silicon dioxide is stronger than the attraction between temporary dipoles present in solid carbon dioxide.

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ERIC Full Text Provided by ERIC

F1-8
70
B

Graphite is suitable for use as an electrode material in electric furnaces and arc lights because it has a high electrical conductivity.

The structure of graphite is best classified as

A a covalent network lattice.
B a covalent layer lattice.
C a molecular lattice.
D an ionic network lattice.
E an ionic layer lattice.

F1-9
70
B

The bonding in graphite is best described as

A ionic within the layers; covalent between layers.
B covalent within the layers; dispersion forces between layers.
C ionic within the layers; dispersion forces between layers.
D covalent within the layers; ionic between layers.

F1-10
60
A, B

Which **one or more** of the following compounds contains covalent bonds?

A C (graphite) **B** SiC(s) **C** $CaCl_2(s)$ **D** Mg(s)

F1-11
70
D

A set of oxides in which the bonding present is essentially covalent in each case is

A $Na_2O_2(s)$, $N_2O_5(g)$, NO(g).
B $Li_2O(s)$, $Al_2O_3(s)$, $P_4O_{10}(s)$.
C $NO_2(g)$, $N_2O_5(g)$, MgO(s).
D $NO_2(g)$, $SiO_2(s)$, $P_4O_{10}(s)$.

F1-12
70
A

A substance which melts at 1700 °C is a poor electrical conductor in both the solid and liquid states. The solid state structure of the substance is most likely to be

A a covalent network lattice.
B a metallic lattice.
C an ionic lattice.
D a molecular lattice.

F2 Ionic lattice solids

F2a Electrovalencies and formulae

F2a-1
60
C

The element samarium (Sm) forms the carbonate $Sm_2(CO_3)_3$. The charge on the samarium ion in this compound is

A −6. **B** −3. **C** +3. **D** +6.

F2a-2
40
A

The valency of the cation in $K_2Cr_2O_7$ is

A +1. **B** +2. **C** +6. **D** −2.

F2a-3
90
B

The metallic element europium, Eu, has a valence of three. The formula of europium oxide would be

A Eu_3O_2. **B** Eu_2O_3. **C** EuO_3. **D** Eu_3O.

F2a-4
70
A

Which one of the following formulae is **incorrect**?

A Al_2CO_3 **B** $KHSO_4$ **C** $Mg_3(PO_4)_2$ **D** $NaNO_3$

F2a-5
90
D

The formula for aluminium sulfate is

A Al_3SO_4. **B** Al_2SO_4. **C** $Al(SO_4)_3$. **D** $Al_2(SO_4)_3$.

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The next two items refer to the following information:

Element Y forms an ionic compound of formula $Y(OH)_2$ which contains hydroxyl ions.

F2a-6 90 **A**

Y could be

A calcium. **B** aluminium. **C** silver. **D** lithium.

F2a-7 40 **C**

An orthophosphate of Y would be likely to have the formula

A Y_2PO_4. **B** $Y(PO_4)_2$. **C** $Y_3(PO_4)_2$. **D** Y_3PO_4. **E** YPO_4.

F2a-8 60 **A**

A metal M readily forms a nitrate with the formula MNO_3. Which of the following compounds is M **least** likely to form?

A MCO_3 **B** M_2SO_4 **C** MOH **D** MH_2PO_4

F2a-9 90 **D**

Chromium nitrate and sodium selenate have the formulae $Cr(NO_3)_3$ and Na_2SeO_4 respectively.

From this information the formula for chromium selenate is

A $CrSeO_4$. **B** Cr_2SeO_4. **C** $Cr(SeO_4)_3$. **D** $Cr_2(SeO_4)_3$.

F2b Electronic structure and formulae

F2b-1 80 **C**

Element X has an electronic configuration of 2, 8, 2. It is likely to form the compound

A Ca_3X_2. **B** MgX. **C** XSO_4. **D** $X_2(PO_4)_3$.

F2b-2 70 **C**

If element Z has an atomic number of 4, then the element

A contains four outer-shell electrons.
B exhibits an electrovalency of 4.
C forms an oxide of formula ZO.
D forms a chloride of formula ZCl_4.

F2b-3 50 **A**

Element Q forms the stable compound $Q(NO_3)_2$. Q could have the electronic structure

A $1s^2 2s^2 2p^6 3s^2$.
B $1s^2 2s^2 2p^6 3s^2 3p^2$.
C $1s^2 2s^2 2p^6 3s^2 3p^4$.
D $1s^2 2s^2 2p^6 3s^2 3p^6$.

F2b-4 50 **B**

If an atom X has one electron in its outer electron shell and atom Y has five electrons in its outer electron shell, then the most probable formula for a compound formed between X and Y is

A XY. **B** X_3Y. **C** X_5Y. **D** XY_5.

F2b-5 60 **A**

Elements W, X, Y and Z have the following electronic configurations:

Element W	2, 6
Element X	2, 4
Element Y	2, 8, 1
Element Z	2, 2

Which of the following compounds is most likely to be stable?

A Y_2W **B** Z_2W **C** Z_2X **D** Y_2Z

F2b-6 90 **C**

An element X is in group I of the periodic table and an element Y is in group VI. A compound formed by the two elements is likely to have the empirical formula

A XY_3. **B** X_2Y_3. **C** X_2Y. **D** X_6Y. **E** XY_6.

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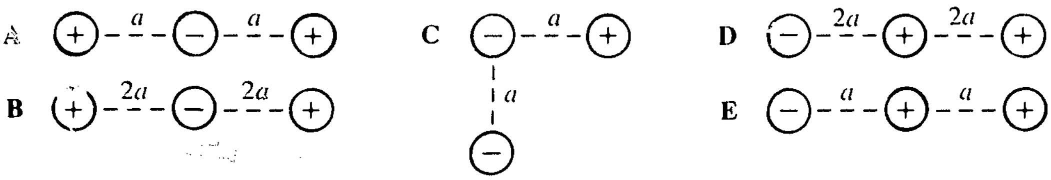
F2b-7 80 B | An element (M) forms compounds with the formulae M_2O_3 and $NaM(OH)_4$. Referring to the periodic table, this element (M) would probably be in

A group I. **B** group III. **C** group V. **D** group VII.

F2c The ionic bond

F2c-1 30 A | Which of the following arrangements of three charged particles is the one with the lowest potential energy?



F2c-2 70 C | The formation of an ionic compound from a reaction between two elements involves

A sharing of pairs of electrons between atoms.
B donation of valence electrons to the entire crystal lattice.
C transfer of electrons between atoms.
D ionization of the atoms of the more electronegative element.

F2c-3 70 B | Atoms of elements may gain or lose electrons to form simple ions in chemical reactions. Statements **A-D** relate this property to the position of particular elements in the periodic table.

Which one of the following is most nearly **correct?**

A Positive ions are formed by elements on the left side and on the right side of the table.
B Elements on the left side of the table form positive ions and those on the right side form negative ions.
C Elements on the left side of the table form negative ions and those on the right side form positive ions.
D There is no relationship between ion charge and the position of an element in the table.

The next three items refer to the following information

For each of the next three items, select from the key the group in the periodic table to which the element would most probably belong.

Key: **A** group I
B group II
C group VI
D group VIII

F2c-4 90 B | An element which forms compounds by losing two electrons.

F2c-5 80 C | An element which forms compounds by gaining two electrons.

F2c-6 70 A | An element which forms ionic compounds with oxygen of the general formula M_2O.

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F2c-7
40
D

Element A (electronic configuration 2, 8, 2) reacts with element X (electronic configuration 2, 7) to form a compound of empirical formula AX_2. From this information it is probable that

A electrons are shared between one atom of element A and two atoms of element X in the molecule AX_2.
B compound AX_2 has characteristics of a covalent crystal lattice.
C each atom of element X has gained two electrons.
D each atom of element A has lost two electrons.

F2c-8
60
C

Exposure of aluminium metal to the atmosphere rapidly produces a surface layer of aluminium oxide, Al_2O_3.

The electronic configuration of oxygen in Al_2O_3 is

A 2, 6. **B** 2, 7. **C** 2, 8. **D** 2, 8, 6.

F2c-9
70
A

An element has an atomic number of 20. When the element reacts to form an ionic compound its electronic configuration will become

A 2, 8, 8. **B** 2, 8, 8, 2. **C** 2, 8, 8, 4. **D** 2, 8, 10.

The next four items refer to the following information

H, P, Q and R represent hydrogen and three other elements. All are in the first three periods of the periodic table. The ionic compound PR_2 and the molecular covalent compound QH_3 are known to exist.

F2c-10
90
A

If P^{2+} and R^- both have the same electronic configuration as a neon atom, then the compound PR_2 is

A magnesium fluoride. **C** calcium fluoride.
B calcium chloride. **D** sodium chloride.

F2c-11
50
C

If PR_2 dissolves in water the mole ratio of negative ions to positive ions in solution would be

A 1:1. **B** 1:2. **C** 2:1. **D** variable.

F2c-12
80
B

Compared with the conductivity of molten PR_2 the conductivity of liquid QH_3 would be expected to be

A high. **B** low. **C** the same as PR_2.

F2c-13
80
D

If atoms of P and Q combined, the formula of the resulting compound would most likely be

A PQ_3. **B** P_3Q. **C** P_2Q_3. **D** P_3Q_2.

The next three items refer to the following information

Element F is a metal, and its atoms have 2 electrons in the outer shell. Element G is a non-metal, and its atoms have 7 electrons in the outer shell. F can combine with G to form a compound.

F2c-14
80
A

The bonds in the compound of F and G are likely to be

A ionic. **B** covalent. **C** polar covalent. **D** metallic.

F2c-15
80
A

What is the most likely formula for the compound of F and G?

A FG_2 **B** F_2G **C** F_2G_7 **D** F_7G_2

F2c-16
60
B

If 6 particles of G surround 1 particle of F in this compound, the number of particles of F surrounding 1 particle of G is

A 1. **B** 3. **C** 6. **D** 12.

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F2c-17 80 A

A compound is formed when element X (atomic number = 12) is heated with element Z (atomic number = 9). The compound formed would be

A ionic, of formula XZ_2.
B ionic, of formula XZ.
C covalent, of formula XZ.
D covalent, of formula XZ_2.

F2c-18 90 D

The electronegativities of different pairs of elements are given below. Which pair of elements is likely to react to form an ionic compound?

A $P(3.5)$ and $Q(4.0)$
B $R(2.5)$ and $S(3.5)$
C $T(0.9)$ and $U(1.2)$
D $V(1.0)$ and $W(3.0)$

F2c-19 60 C

In which of the following are types of chemical bonds listed in **increasing** order of strength?

A hydrogen bonds, dipole-dipole attractions, ionic bonds
B covalent bonds, dispersion forces, hydrogen bonds
C dispersion forces, hydrogen bonds, ionic bonds
D dispersion forces, hydrogen bonds, dipole-dipole attractions

F2d Common ionic compounds

F2d-1 40* D

Which one of the following substances contains ions in the solid state?

A hydrogen chloride
B silicon dioxide
C carbon tetrachloride
D calcium oxide

F2d-2 70* C

Of the following, the best description of the crystal structure of sodium chloride is

A an array of negatively charged sodium ions and positively charged chloride ions held together by electrostatic forces in a cubic lattice
B six sodium atoms surrounded by six chlorine atoms, and six chlorine atoms surrounded by six sodium atoms, arranged in a cubic lattice
C an array of positively charged sodium ions and negatively charged chloride ions arranged in a cubic lattice
D an array of diatomic sodium chloride molecules

F2d-3 60 B

Which of the following statements best describes the structure of solid calcium chloride?

A a lattice consisting of diatomic chlorine molecules strongly bonded to calcium atoms
B a lattice of calcium and chloride ions in the ratio of one to two, strongly bonded
C discrete molecules of calcium chloride with strong bonding within the molecules but weak intermolecular bonding
D an infinite lattice in which calcium and chlorine are linked by strong covalent bonds

F2d-4 60 C

The structure and bonding in solid magnesium oxide is best described as

A MgO molecules which are ion-pairs, $Mg^{2+}O^{2-}$, packed into a lattice and held together by dipole-dipole and dispersion force interactions.
B MgO molecules which are ion-pairs, $Mg^{2+}O^{2-}$, packed into a lattice and held together by a sea of electrons moving around the Mg^{2+}.
C Mg^{2+} and O^{2-} ions packed into a lattice and held together by the electrical attraction between positive and negative ions.
D Mg atoms and O atoms packed into a lattice held together by a sea of electrons.
E Mg atoms and O atoms packed into a lattice held together by Mg-O covalent bonds.

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F2d-5 70 A | Sodium chloride, silicon dioxide and diamond all melt at high temperatures. Which one of the following statements is true of all three solids?

A There is strong bonding between particles in all directions.
B There is ionic bonding between particles.
C There is covalent bonding between particles.
D There is strong bonding between atoms but weak bonding between the molecules.

F2d-6 40 B | One of the following compounds exists as an ionic lattice in the solid state. Which one?

A CH_3Cl **B** NH_4Cl **C** HCl **D** SiO_2

F2d-7 60 C | Some substances contain both ionic and covalent bonds. They include

A $MgF_2(s)$. **B** $CH_3Cl(l)$. **C** $NaNO_3(s)$. **D** $CH_3NH_2(l)$.

F2e Properties of ionic compounds

F2e-1 50* D | An ionic substance can be distinguished from metallic and molecular substances by measuring the electrical conductivity of the substance in

A the solid state only.
B the liquid state only.
C an aqueous solution only.
D the solid and liquid states.
E the solid state and in an aqueous solution.

F2e-2 60* D | A major difference between ionic compounds and molecular compounds is that ionic compounds

A dissolve in water whereas molecular compounds are insoluble.
B usually form crystals whereas molecular compounds usually do not.
C conduct electricity in the solid state whereas molecular compounds do not.
D usually melt at higher temperatures than molecular compounds.

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The next three items refer to the following information:

Three solid substances were tested in three ways:

Solid substance	*Test 1* Hit a small lump of the substance with a hammer	*Test 2* Place substance in a crucible and heat gently	*Test 3* Test some of the substance for electrical conductivity
I	flattened	melted easily	non-conductor in both the solid and liquid state
II	shattered	no visible change	non-conductor in the solid state; conducted electricity in the liquid state
III	shattered	melted easily	non-conductor in both the solid and liquid state

Use the following key to identify the most probable chemical structure of each of the solid substances, I-III:

Key: **A** metallic lattice
B ionic lattice
C covalent network lattice
D discrete molecules

F2e-3 50 **D** I

F2e-4 80 **B** II

F2e-5 40* **D** III

F2e-6 50 **C** A characteristic property of ionic solids is that they are

A ductile.
B malleable.
C brittle.
D good electrical conductors.

F2e-7 40 **D** The following table presents some properties of five compounds.

	Electrical conductivity of solid	Electrical conductivity when molten	Melting point /°C
I	poor	poor	8.4
II	good	good	98
III	good	good	1083
IV	poor	good	810

The compound most likely to consist of an aggregate of ions in the solid state is

A I. **B** II. **C** III. **D** IV.

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The next two items refer to the following information

Some of the properties of the pure substances *W*, *X*, *Y* and *Z* are given below.

Substance	Hardness of solid	Melting temperature /°C	Electrical conductivity of solid	Electrical conductivity of solution
W	soft	−114	negligible	high
X	soft	18	negligible	negligible
Y	hard	810	negligible	high
Z	hard	2700	negligible	not measured (insoluble)

F2e-8 50 **D**

The substance which is most likely to have a covalent network lattice structure in the solid state is

A *W*. **B** *X*. **C** *Y*. **D** *Z*.

F2e-9 70 **C**

The substance which is most likely to contain ionic bonds is

A *W*. **B** *X*. **C** *Y*. **D** *Z*.

F2e-10 60 **B**

A solid has the following properties:

melting temperature	770 °C
solubility in water	340 g dm^{-3}
electrical conductivity of solid	low
electrical conductivity of solution	high

The structure of the solid is probably

A a covalent network lattice.

B an ionic lattice.

C a metallic lattice.

D a molecular crystal.

F2e-11 70 **D**

Which one of the following statements would **not** be true of the compound $CaCl_2$?

A It is brittle and crystalline in the solid state.

B It conducts electricity when melted.

C It is a poor conductor of electricity in the solid state.

D It is very soluble in carbon tetrachloride.

F2e-12 70 **C**

Which one of the following materials would be the poorest conductor of electricity?

A molten potassium fluoride

B graphite

C solid sodium chloride

D an aqueous solution of lithium fluoride

F2e-13 70 **C**

Which of the following substances is the best electrical conductor when molten?

A phosphorus(V) oxide

B carbon tetrachloride

C potassium fluoride

D silicon dioxide

F3 Metallic solids

F3a The metallic bond

F3a-1 70* **C**

A characteristic of metallic elements is that

A their atoms usually share electrons with atoms of non-metals.

B their electronegativities are high, which means they lose electrons easily.

C their atoms have only a small number of electrons in the valence shell and these can be removed relatively easily.

D in the solid state electrostatic forces are not important since strong metallic bonds hold the atoms together.

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F3a-2 70 B

The structure of a metal crystal can be described as a lattice of

- **A** atoms covalently bonded to one another.
- **B** positive ions with the excess electrons forming an electron cloud dispersed through the lattice.
- **C** atoms with positively and negatively charged ions dispersed through the lattice.
- **D** positively charged and negatively charged ions alternating through the lattice.

F3a-3 60 D

The structure and bonding in solid potassium metal at room temperature and pressure is best described as

- **A** a lattice of diatomic (K_2) molecules with covalent bonding between the atoms and strong dispersion forces between the molecules.
- **B** a lattice of diatomic (K_2) molecules with covalent bonding between the atoms and strong dipolar forces between the molecules.
- **C** a network lattice of close packed potassium atoms, held together by strong covalent bonds.
- **D** a network lattice of potassium ions, held together by a cloud of electrons.

F3a-4 70 A

The solid state structure of an element with the electronic configuration

$$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^1 5s^2$$

is best described as

- **A** a metallic lattice.
- **B** a molecular lattice.
- **C** an ionic lattice.
- **D** a covalent network lattice.

F3a-5 50 A

Which of the following best describes conditions necessary for atoms to form metallic bonds?

- **A** vacant outer-shell electron orbitals and low ionization energies
- **B** vacant outer-shell electron orbitals and high ionization energies
- **C** filled outer-shell electron orbitals and low ionization energies
- **D** filled outer-shell electron orbitals and high ionization energies

F3a-6 90 A

The electronic configurations of elements *P*, *Q*, *R*, and *S* are

P $1s^2 2s^2 2p^6 3s^2 3p^1$
Q $1s^2 2s^2 2p^6 3s^2 3p^6$
R $1s^2 2s^2 2p^4$
S $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$

Which element is a metal?

A *P* **B** *Q* **C** *R* **D** *S*

F3a-7 80 B

The atomic numbers of four elements are listed below. Which atomic number corresponds to an element with metallic bonds?

A 2 **B** 12 **C** 17 **D** 18

F3a-8 70 D

The electronegativity values of elements *P*, *Q*, *R* and *S* are given below. Which element is most likely to be a metal?

- **A** element *P* : 4.0
- **B** element *Q* : 3.0
- **C** element *R* : 2.2
- **D** element *S* : 1.0

F3b Common metallic solids

F3b-1 30 A, C, F

Which **one or more** of the following substances contain(s) metallic bonding?

- **A** lithium
- **B** silicon carbide
- **C** calcium
- **D** sulfur
- **E** neon
- **F** mercury
- **G** sodium fluoride

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F3b-2 At temperatures less than 180 °C at atmospheric pressure, lithium exists as a crystalline solid. Lithium atoms are held together in the solid mainly by
60
D

A covalent bonding.
B ionic bonding.
C dispersion forces.
D metallic bonding.

F3c Properties of metals

F3c-1 Copper wire may be bent easily without breaking. The best explanation of this is that
50
B

A the forces between copper atoms are weak, allowing the copper particles to be easily moved around.
B slight changes in relative positions of adjacent copper particles do not break the metallic bonds as these are equally strong in all directions.
C copper particles are strongly bonded in layers but only weakly bonded between layers.
D copper particles are arranged in flat molecules which freely slide over each other, allowing the material to be bent.

F3c-2 The physical properties of solid metals can best be explained by proposing that
70
B

A each metal atom is bonded in the crystal lattice by covalent bonds.
B positive metal ions are arranged in an orderly way, with valence electrons able to move freely through the crystal lattice.
C positive and negative metal ions are arranged in an orderly way, with mobile valence electrons able to migrate easily around the crystal lattice.
D each metal atom is surrounded by a variable number of valence electrons, which complete a 'noble gas' electronic structure in the crystal lattice.

F3c-3 If a material is described as 'ductile' it means that the material
70
D

A is very flexible.
B has a high density.
C can be rolled into thin sheets.
D can be drawn out into wires.

F3c-4 Metals are almost unique in being able to conduct electricity in the solid state. Metals conduct electricity because their
90
B

A ions move easily through the crystal lattice.
B outer-shell electrons move easily through the crystal lattice.
C protons move easily through the crystal lattice.
D atoms are closely packed.

F3c-5 A substance which melts at 1640 °C conducts electricity in both the solid and liquid states.
80
D

The solid state structure of the substance is **most** likely to be

A an ionic lattice.
B a covalent network lattice.
C a molecular lattice.
D a metallic lattice.

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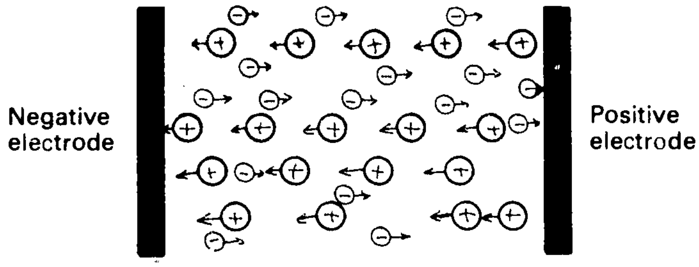
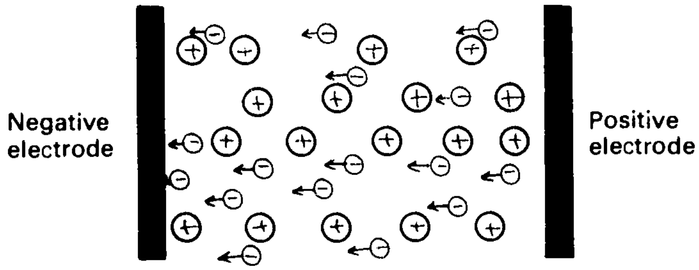
F3c-6 Which of the diagrams below best represents the motion of particles within a piece of metal connected to the positive and negative terminals of a battery?
40
D

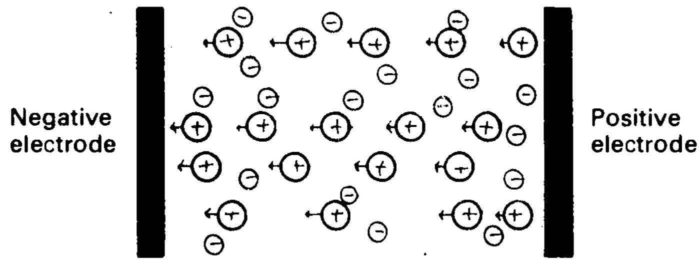
A



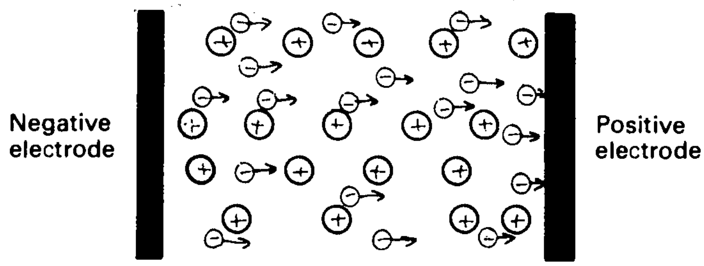
B



C



D



F3d Alloys

F3d-1 The structure of a solid formed by heating a mixture of two metallic elements at high temperature is likely to be
80*
A

A a metallic lattice.
B a molecular lattice.
C an ionic lattice.
D a covalent network lattice.

F3d-2 Brass is an alloy formed by combining
50
B

A copper and tin.
B copper and zinc.
C zinc and tin.
D tin and lead.
E copper and lead.

F3d-3 Which **two** of the following elements are most likely to form an alloy when heated together?
60
A,C

A copper **B** phosphorus **C** zinc **D** sulfur **E** iodine

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F3d-4
80
A

Steel is an alloy of iron and carbon.
The reason that carbon is present in steels is to

A increase hardness and tensile strength.
B increase ductility and ability to be welded.
C increase electrical conductivity.
D reduce the rate of corrosion.

F4 Miscellaneous bonding items

F4-1
50
E

One or more of the following bond types are electrostatic in nature. Which one(s)?

A ionic bonds
B metallic bonds
C covalent bonds
D hydrogen bonds
E all of the above

The next two items refer to the following information

The electronic configurations of elements *W*, *X*, *Y* and *Z* are given below.

W $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$
X $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$
Y $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^5$
Z $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$

F4-2
40
B

Which one of the following pairs of elements is most likely to react to fo·m an ionic compound?

A *W* and *X* **B** *W* and *Y* **C** *W* and *Z* **D** *X* and *Z*

F4-3
70
B

Which one of the following pairs of elements is most likely to form an alloy when heated together?

A *W* and *Y* **B** *W* and *Z* **C** *X* and *Y* **D** *X* and *Z*

The next three items refer to the following information

When elements combine to form a compound the following types of bonds may be formed:

I metallic bond
II ionic bond
III polar covalent bond
IV non-polar covalent bond

F4-4
80
C

The bond formed between two atoms, one in group V, the other in group VII, would be

A I. **B** II. **C** III. **D** IV.

F4-5
90
B

The bond formed between two atoms, one in group I, the other in group VI, would be

A I. **B** II. **C** III. **D** IV.

F4-6
70
A

The bond between two atoms, both having low electronegativities, would be

A I. **B** II. **C** III. **D** IV.

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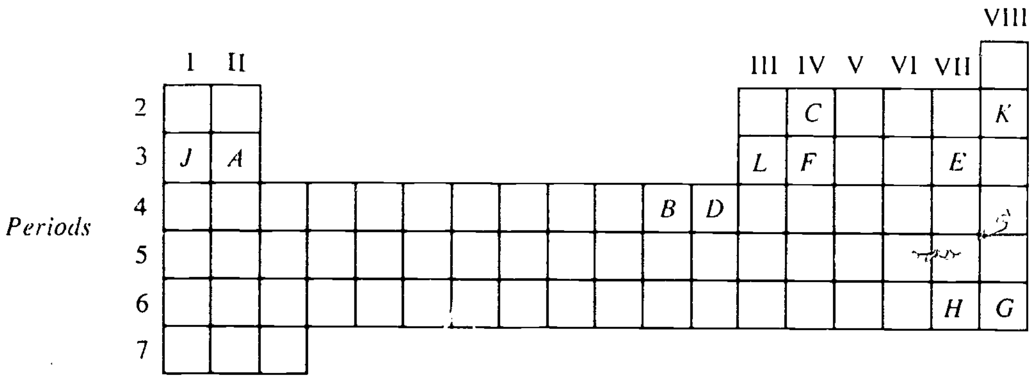
The next four items refer to the following information:

A section of the periodic table is represented by the diagram below. The locations of particular elements are indicated by letters which are not their usual symbols.



F4-7 80 C — Which of the following pairs of elements is most likely to form an alloy?

A *A* and *E* **B** *M* and *F* **C** *B* and *D* **D** *G* and *H*

F4-8 70 D — Which of the following pairs of elements is most likely to form an ionic compound?

A *A* and *G* **B** *J* and *K* **C** *M* and *F* **D** *A* and *E*

F4-9 80 B — Which one of the following elements could have a melting temperature of 660 °C and be a good conductor of electricity?

A *E* **B** *L* **C** *G* **D** *F*

F4-10 80 D — Which one of the following pairs of elements would form a molecular compound?

A *J* and *A* **B** *D* and *L* **C** *E* and *K* **D** *M* and *E*

The next three items refer to the following information

The electrical conductivities of several substances are tabulated below.

	Electrical conductivity		
Substance	of solid	of liquid	of aqueous solution
P	low	low	high
Q	low	high	high
R	low	low	low
S	low	low	*
T	high	high	*

* *S* and *T* are insoluble in water

F4-11 50 C — Which **one or more** of the following substances could *P* be?

A KF **B** SiO_2 **C** HCl **D** Ag

F4-12 80 E — Which substance is most likely to be able to be hammered into a thin sheet?

A *P* **B** *Q* **C** *R* **D** *S* **E** *T*

F4-13 20 B,C — Which **one or more** of the following substances could be molecular solids?

A *Q* **B** *R* **C** *S* **D** *T*

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G GASES

G1 Kinetic theory of gases

G1-1 70 D

It can be shown that the kinetic theory of gases leads logically to the concept of an absolute zero of temperature. Which of the following is **not** a consequence of the existence of an absolute zero of temperature?

As the temperature of an ideal gas approaches absolute zero

A the volume of the gas approaches zero.
B the kinetic energy of the molecules of the gas approaches zero.
C the pressure of the gas approaches zero.
D the mass of the gas approaches zero.

G1-2 80 A

Given that SO_2 is a gas under laboratory conditions, which of the following statements is **least** likely to be true of a sample of SO_2?

A The volume of the sample would be zero at the absolute zero of temperature.
B The pressure exerted by gaseous SO_2 is due to the collisions of molecules of SO_2 with the walls of the containing vessel.
C Molecules of gaseous SO_2 are always in random motion.
D The average kinetic energy of molecules of gaseous SO_2 is proportional to the absolute temperature of the gas.

G1-3 70 C

Gases are much more easily compressed than liquids or solids. The reason for this behaviour is that

A gas molecules move with much greater velocities than the molecules of liquids and solids, permitting gases to adjust more rapidly to a change in volume.
B gas molecules undergo elastic collisions with the walls of a container and elastic substances are easily compressed.
C the average distance between gas molecules is much greater than that between particles in liquids or solids, so the volume may be more easily reduced.
D attractive forces between gas molecules are much smaller than those between particles in solids and liquids, and these small forces can be readily overcome during compression.

G1-4 50 C

A weather balloon increases in volume many times in ascending to high altitudes. In terms of the kinetic molecular theory, the expansion of the balloon is due to

A a reduction in the mean kinetic energy of the particles of the atmosphere.
B an increase in the rate of collisions of particles against the inside walls of the balloon.
C a decrease in the rate of collisions of particles in the atmosphere on the outside walls of the balloon.
D an increase in the mean kinetic energy of particles inside the balloon.

G2 Molecular speeds

G2-1 30 B

A sample of air is maintained at a constant temperature of 20 °C.

Which of the following statements about the molecules of nitrogen and oxygen in the sample is correct?

A The average kinetic energy of the nitrogen molecules is greater than the average kinetic energy of the oxygen molecules.
B The average speed of the nitrogen molecules is greater than the average speed of the oxygen molecules.
C The molecules of nitrogen and oxygen are moving at the same average speeds.
D The average kinetic energy of the oxygen molecules is greater than the average kinetic energy of the nitrogen molecules

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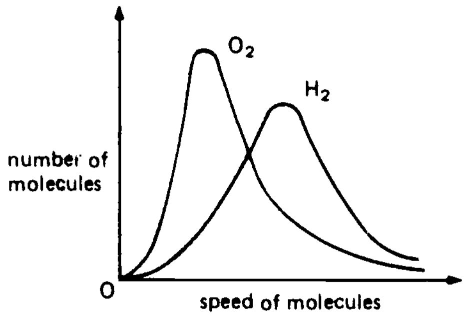
G2-2 20* A

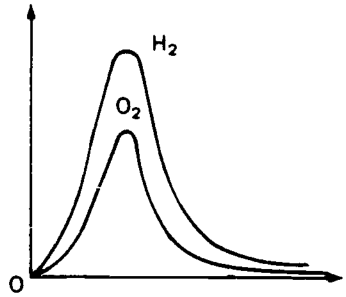
Consider equal numbers of molecules of hydrogen, H_2 (M_r = 2), and oxygen, O_2 (M_r = 32), which are at the same pressure and temperature.

Which one of the following diagrams best shows the speed distribution for these two gases?

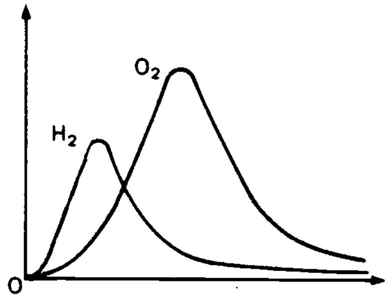
A



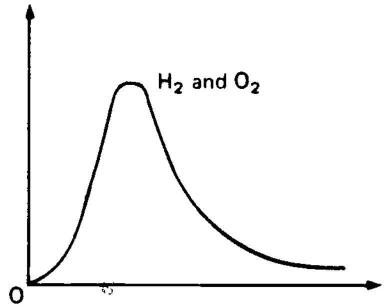
C



B



D



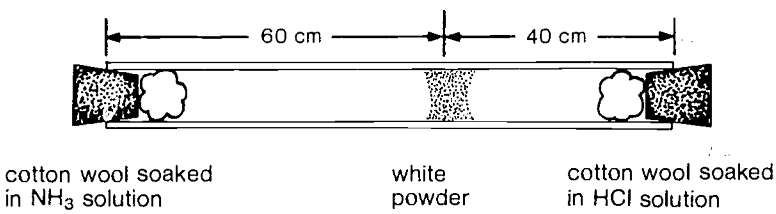
G2-3 30 A

If small samples of the following gases were released in a sealed room, which gas would be expected to spread most rapidly throughout the room?
(A_r: U=238, Ne=20, F=19, O=16, N=14, C=12)

A neon **B** oxygen **C** nitrogen **D** uranium hexafluoride

G2-4 50 D

Ammonia (M_r = 17.0) and hydrogen chloride (M_r = 36.5) are gases at room temperature and pressure. Plugs of cotton wool were soaked in concentrated solutions of each of the two gases and placed at opposite ends of a horizontal one metre glass tube. After some time a white cloud of ammonium chloride powder appeared at the position shown in the diagram.



Which of the following statements best accounts for the position where the powder is formed?

A The average kinetic energy of the ammonia molecules is greater than the average kinetic energy of the hydrogen chloride molecules.

B The larger hydrogen chloride molecules are involved in more collisions per unit time and diffuse more slowly than ammonia molecules.

C The average kinetic energy of the ammonia molecules is less than the average kinetic energy of the hydrogen chloride molecules.

D The average velocity of the hydrogen chloride molecules is less than the average velocity of the ammonia molecules.

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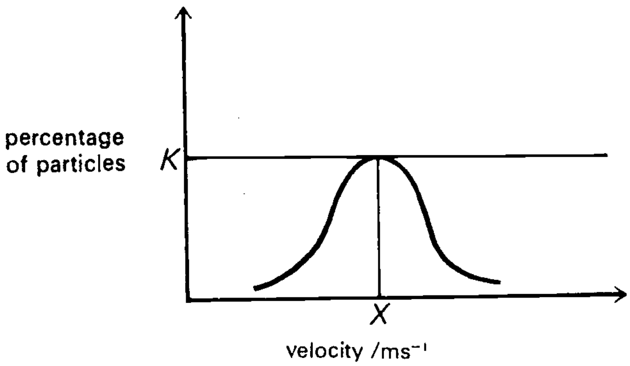
G2-5
60
C

As the temperature of a gas increases

A each gas particle moves faster than any particle did before.
B some gas particles reach their escape velocity.
C many particles of the gas move faster than they did before.
D individual particles do not change in velocity but their mean velocity increases.

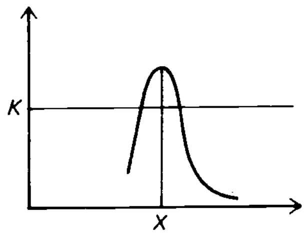
G2-6
20
B

The following graph represents the distribution of particle velocities expected in a certain gas at 20 °C.

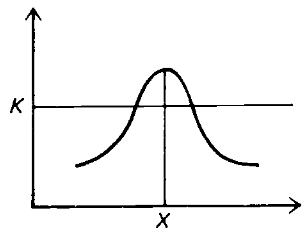


Which of the following graphs shows the expected distribution of particle velocities in the same gas at 100 °C?

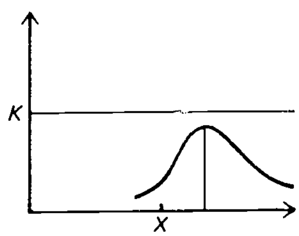
A



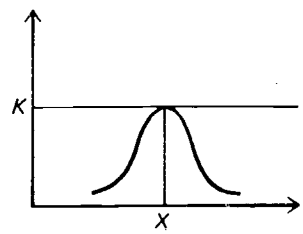
C



B



D



G3 Relationship between pressure and volume

G3-1
70
D

In 1662 Robert Boyle investigated the behaviour of gases. He discovered that

A the volume of a sample of gas changes by $\frac{1}{273}$ of its volume for every 1 °C change in its temperature.
B the volume of a gas is proportional to the amount of gas at constant temperature and pressure.
C the average kinetic energy of the gas molecules is proportional to the absolute temperature of the gas.
D the pressure of a sample of gas is inversely proportional to the volume at constant temperature.

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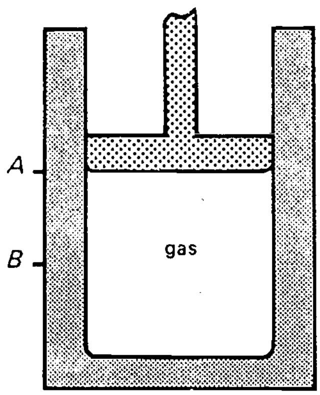
The diagram shows a container filled with gas and sealed by a movable piston.



There is sufficient gas to support the piston at point *A* at 15 °C.

G3-2 60 **C**

When the gas is heated, assuming the piston can move freely, the pressure which the gas reaches will

A increase.
B decrease.
C be the same.
D change in an unpredictable manner.

G3-3 90 **A**

With the same apparatus at a constant 15 °C the piston is pushed down to point *B* so that the volume is halved. The average number of molecules striking a unit area of the wall of the container per unit time will

A double.
B halve.
C remain the same.
D change in an unpredictable manner.

G3-4 90* **A**

At 20 °C, 300 cm^3 of a gas has a pressure of 1.024×10^5 Pa. The gas is allowed to expand into a second vessel at the same temperature, until the total volume is 450 cm^3. The pressure is now

A $\frac{300}{450} \times 1.024 \times 10^5$ Pa.
B $\frac{450}{300} \times 1.024 \times 10^5$ Pa.
C $\frac{150}{300} \times 1.024 \times 10^5$ Pa.
D $\frac{300}{450 \times 1.024 \times 10^5}$ Pa.

G3-5 80 **B**

As a man dives into the sea the pressure of gas in his lungs changes from 100 000 Pa to 150 000 Pa. If his lungs initially held 6 dm^3 of gas, the volume of his lungs would become

A 3 dm^3. **B** 4 dm^3. **C** 6 dm^3. **D** 9 dm^3.

G3-6 70 **C**

A boy closes the outlet of a bicycle pump with his finger and pushes down the plunger. When the volume of air in the pump is reduced to 20 cm^3 his finger is forced off the outlet.

If the pump originally held 90 cm^3 of air and atmospheric pressure is 101 000 Pa, the maximum pressure the boy produced in the pump was

A $\frac{70 \times 101\,000}{20}$ Pa.
B $\frac{20 \times 101\,000}{70}$ Pa.
C $\frac{90 \times 101\,000}{20}$ Pa.
D $\frac{20 \times 101\,000}{90}$ Pa.

G3-7 20 **B**

A bubble of air rises to the surface of the ocean from the floor 30 m below. If the pressure at the ocean surface is 1 atm and the pressure on the air in the bubble decreases by 1 atm every 10 m it travels, the ratio

volume of bubble at ocean floor: volume of bubble at surface

is approximately

A 1:3. **B** 1:4. **C** 3:1. **D** 4:1.

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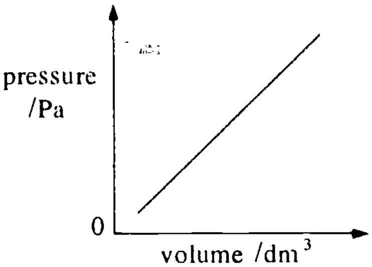
G3-8 The following data refer to a sample of hydrogen gas:
60
D

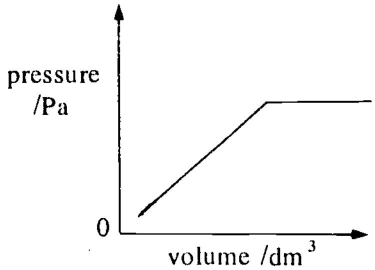
Pressure	Volume	Temperature
10^5 Pa	0.316 dm^3	20.0 °C
10^5 Pa	0.632 dm^3	313.0 °C
10^5 Pa	0.158 dm^3	−126.5 °C

Which one of the following graphs best depicts the relationship presented in the given data?

A



C



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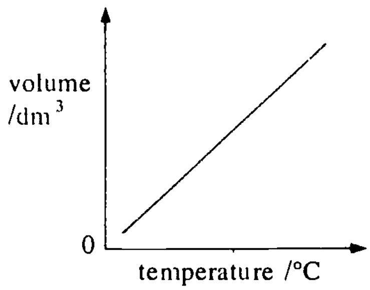

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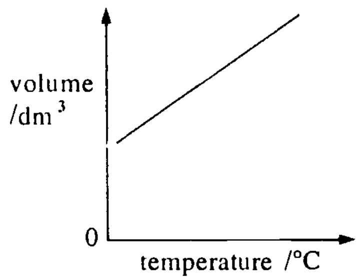
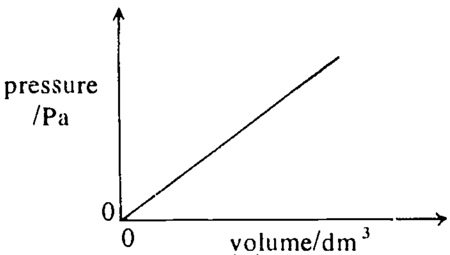


G4 Relationship between temperature and volume (or pressure)

The next two items refer to the following information

I



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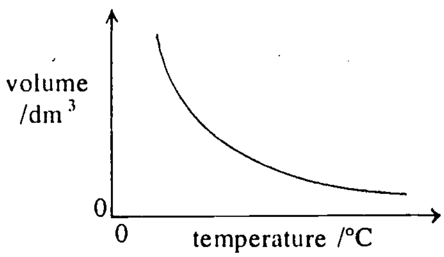
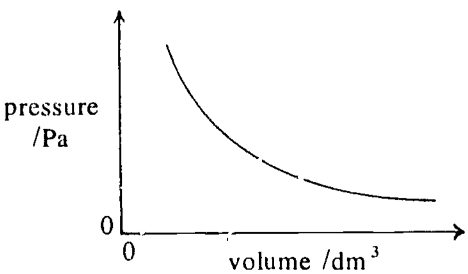
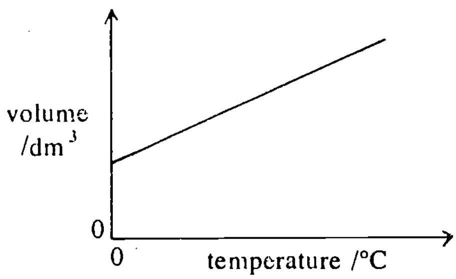


II



IV



The above graphs represent possible plots of pressure against volume at constant temperature, and volume against temperature at constant pressure, for a fixed mass of the same gas.

G4-1 Which graph is the best representation of Boyle's Law?
70
3

A I **B** II **C** III **D** IV

G4-2 Which graph is the best representation of Charles' Law?
60
D

A I **B** II **C** III **D** IV

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G4-3 A gas in a container of fixed volume is heated from 100 °C to 400 °C. Which of the following is the best estimate of what will happen to the pressure of the gas?
40
D

The pressure will

A remain unaltered.
B increase by a factor greater than four.
C increase by a factor of four.
D increase by a factor less than four.

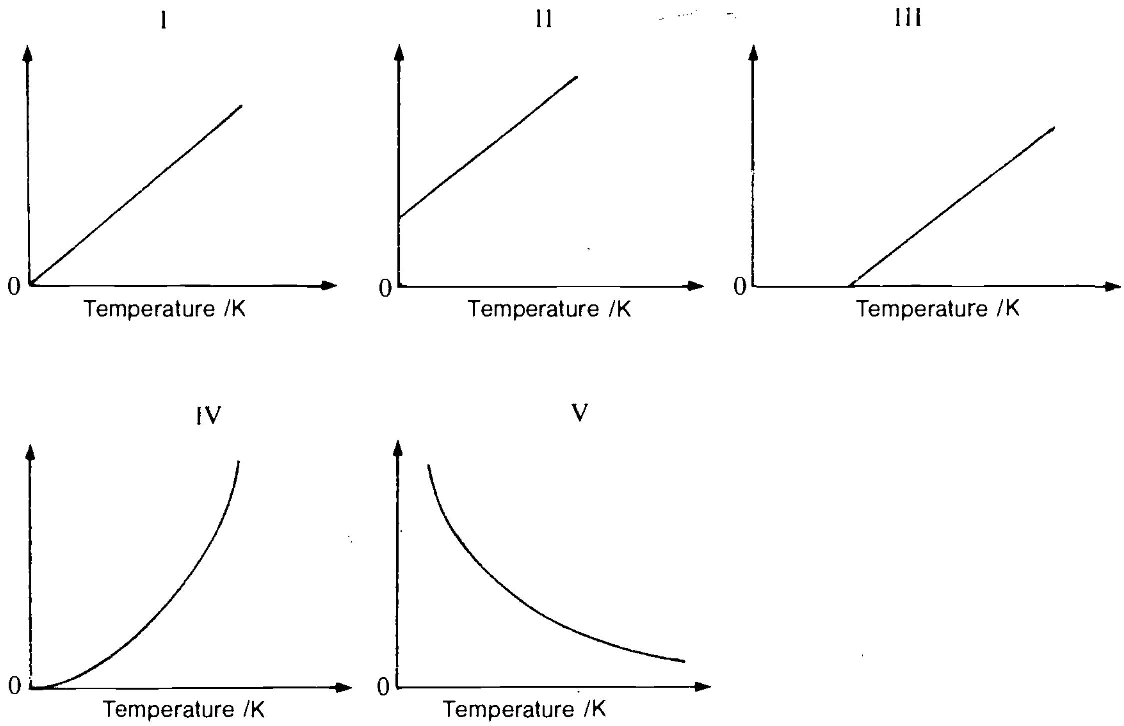
G4-4 A can of gas explodes when the gas pressure reaches 220 kPa. If a can containing gas at 20 °C and 150 kPa pressure is disposed of in an incinerator, it would explode when its temperature reaches
70
B

A $\frac{150}{220 \times 293}$ K.
B $\frac{220 \times 293}{150}$ K.
C $\frac{150 \times 293}{220}$ K.
D $\frac{220}{150 \times 293}$ K.

G4-5 At 0 °C a certain mass of gas occupies 1 dm^3 at atmospheric pressure. At what temperature will this mass of gas occupy 2 dm^3 if the pressure remains constant?
50
A

A 273 °C B 273 K C 1 °C D 100 °C E 0 °C

The next three items refer to the following graphs



G4-6 Which graph best represents the way the volume of a sample of gas varies with absolute temperature, pressure being kept constant?
40
A

A I B II C III D IV E V

G4-7 Which graph best represents the way the pressure of a sample of gas varies with absolute temperature, volume being kept constant?
50
A

A I B II C III D IV E V

G4-8 Which graph best represents the way Celsius temperature varies with absolute temperature?
50
C

A I B II C III D IV E V

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G4-9 70 **A**

A gas fills a 100 cm^3 cylinder fitted with a piston at a particular temperature and pressure. If the volume of the gas is halved by pushing in the piston and, at the same time, the absolute temperature is doubled, then the pressure of the gas will be

A increased four-fold.
B doubled.
C unchanged.
D halved.

G4-10 80 **B**

5 dm^3 of nitrogen is at a temperature of −40 °C, and the pressure of gas is 1.000×10^5 Pa. If one atmosphere pressure is 1.013×10^5 Pa, the volume that the nitrogen would occupy at STP is (in dm^3)

A $5 \times \frac{1.013}{1.000} \times \frac{273}{(273-40)}$.
B $5 \times \frac{1.000}{1.013} \times \frac{273}{(273-40)}$.
C $5 \times \frac{1.000}{1.013} \times \frac{273}{(273+40)}$.
D $5 \times \frac{1.013}{1.000} \times \frac{(273-40)}{273}$.

G4-11 60 **B**

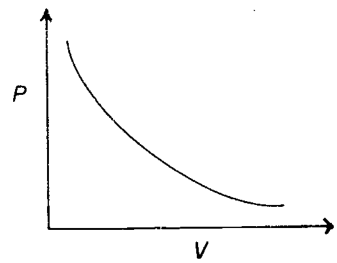
At which of the following conditions would a sample of air have the greatest volume?

A STP (0 °C and 1×10^5 Pa)
B 273 °C and 5×10^4 Pa
C 273 K and 2×10^5 Pa
D −73 °C and 6×10^4 Pa
E 17 °C and 1×10^5 Pa

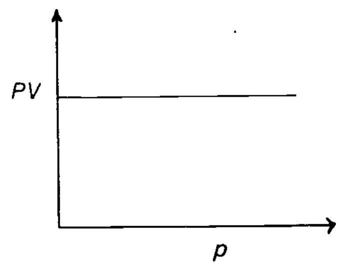
G4-12 40 **D**

At constant temperature, for a given mass of gas, the relationship between pressure and volume can be written as $PV = k$ or $P \propto 1/V$. This relationship can be represented graphically in a number of ways. Which of the following graphs does **not** represent the relationship correctly?

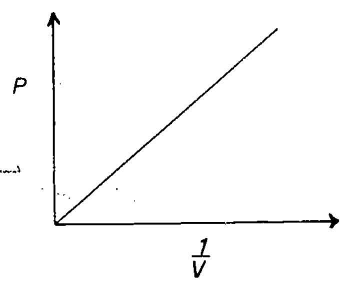
A



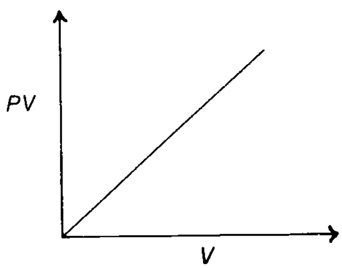
C



B



D



G4-13 30 **B**

For a given sample of an ideal gas, the product of the pressure and volume at constant temperature

A has a fixed value of 8.31.
B has a fixed value independent of the pressure.
C has a value which increases with pressure.
D has a value which decreases with pressure.
E decreases initially with increasing pressure, reaches a minimum and then increases.

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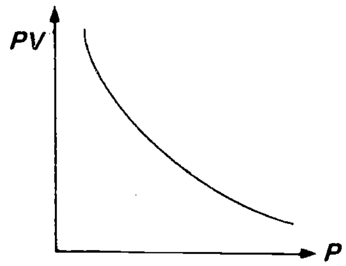
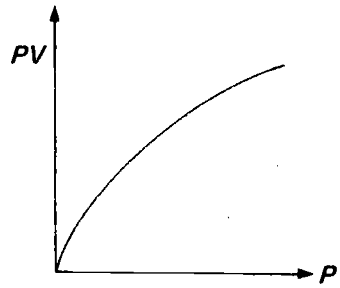
G4-14 | For a sample of an ideal gas, the relationship between the product of pressure and volume (PV) with pressure at constant temperature is best represented by the graph
40
D

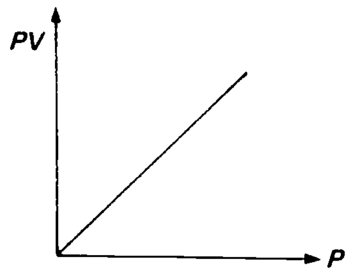
A



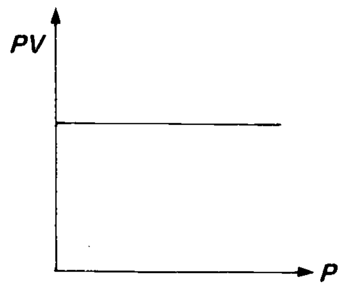
C



B



D



G5 Molar volume

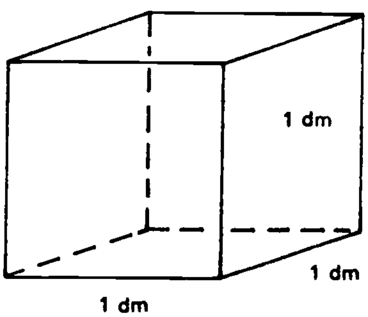
G5-1 | One mole of an ideal gas occupies
10
C

A 22·4 dm^3 at 273 °C and 101 300 Pa pressure.
B 44·8 dm^3 at 546 °C and 101 300 Pa pressure.
C 22·4 dm^3 at 273 °C and 202 600 Pa pressure.
D 44·8 dm^3 at 546 °C and 202 600 Pa pressure.

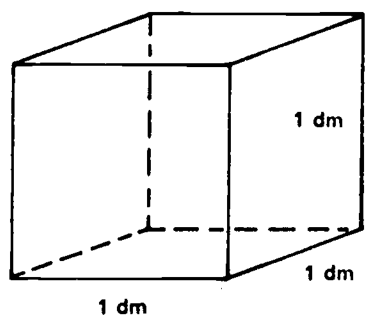
G5-2 | A 1.6 g sample of oxygen gas (A_r = 16.0) has a volume of 5.0 dm^3 at a particular temperature and pressure. The molar volume of oxygen gas under these conditions is
20
D

A 22.4 $dm^3\ mol^{-1}$.
B 32 $dm^3\ mol^{-1}$.
C 50 $dm^3\ mol^{-1}$.
D 100 $dm^3\ mol^{-1}$.

The next two items refer to the following information



Chlorine at 15 °C and
1.00×10^5 Pa pressure



Nitrogen at 15 °C and
1.0×10^5 Pa pressure

(Relative atomic masses: Cl = 35.5, N = 14.0)

G5-3 | The ratio of the number of molecules of chlorine to the number of molecules of nitrogen in each of the containers shown is
80
A

A 1:1 **B** 1:2 **C** 35.5:14.0 **D** 71:28

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G5-4 60 C | The molecules of the gases in the containers have the same average

A molecular volume.
B relative molecular mass.
C kinetic energy.
D velocity.

The next two items refer to the following information

A student had two flasks of identical volume.
He filled flask 1 with 1 mol of gas X ($M_r = 20$) at a temperature of 400 K, and flask 2 with 2 mol of gas Y ($M_r = 80$) at 100 K.

G5-5 60 B | The ratio, pressure of gas X : pressure of gas Y, is equal to

A 4:1. B 2:1. C 1:1. D 1:2. E 1:4.

G5-6 80 D | The ratio, number of molecules in flask 1 : number of molecules in flask 2, is equal to

A 4:1. B 2:1. C 1:1. D 1:2. E 1:4.

G5-7 80 D | Chlorine atoms exist in two isotopic forms: $^{35}_{17}Cl$ and $^{37}_{17}Cl$.
If it were possible to completely separate these isotopes, it would follow that, assuming that all gases behaved ideally,

A 1 mol of $(^{37}_{17}Cl)_2$ gas would occupy a greater volume than 1 mol of $(^{35}_{17}Cl)_2$ gas under the same conditions.
B 1 g of $^{37}_{17}Cl$ would contain more atoms than 1 g of $^{35}_{17}Cl$.
C 1 dm^3 of $(^{37}_{17}Cl)_2$ gas would contain more molecules than 1 dm^3 of $(^{35}_{17}Cl)_2$ gas under the same conditions.
D 1 dm^3 of $(^{37}_{17}Cl)_2$ gas would have a greater mass than 1 dm^3 of $(^{35}_{17}Cl)_2$ gas under the same conditions.

G5-8 30 B | A bulb is filled with helium ($A_r = 4.0$) to 2.0×10^5 Pa pressure, whilst another bulb of the same volume is filled with hydrogen ($A_r = 1.0$) to 1.0×10^5 Pa pressure. If the temperatures of the two gases are the same, which of the following statements is true?

A The mass of the helium sample is twice that of the hydrogen sample.
B There are the same number of helium atoms as there are hydrogen atoms.
C There are twice as many helium atoms present as hydrogen atoms.
D There are the same number of helium atoms as there are hydrogen molecules.

G5-9 40 D | One dm^3 of each of two gases, Y and Z, measured at STP (1.01×10^5 Pa, 0 °C) is passed into a 1 dm^3 container where they react completely to form a new gas compound Q. The pressure of gas Q is found to be 1.01×10^5 Pa at 0 °C. It can be concluded that the number of molecules of Q formed

A equals the total number of molecules in all of the reactants.
B is greater than the number of molecules in any one of the reactants.
C is less than the number of molecules in any one of the reactants.
D equals the number of molecules in any one of the reactants.

G5-10 80 B | A flask, M, contains 1 mol of gas molecules at 250 K.
A flask, N, whose volume is the same as flask M, contains 2 mol of gas molecules. The pressure in flask N, however, is the same as that in flask M.

This could be explained if the gas in flask N

A had half the relative molecular mass of the gas in flask M.
B was at a temperature of 125 K.
C was composed of diatomic molecules.
D had half as many molecules as the gas in flask M.

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G5-11 40 D

The following statements (**A-D**) refer to equal masses of two different gases confined to equal volumes at the same temperature. Which **one** of these statements is definitely true?

A The gas with the higher density will exert the greater pressure.
B The two gases will exert the same pressure.
C The gas with the higher relative molecular mass will exert the greater pressure.
D The gas with the lower relative molecular mass will exert the greater pressure.

G5-12 50 C

The following statements refer to equal masses of gaseous dinitrogen pentoxide, N_2O_5, and gaseous dinitrogen tetroxide, N_2O_4, confined to equal volumes at the same temperature. Assume that neither gas decomposes appreciably at this temperature. (A_r N = 14; O = 16)

Select which one of the statements is correct.

A The two gases will exert the same pressure.
B N_2O_5 will exert the higher pressure.
C N_2O_4 will exert the higher pressure.
D There is insufficient data to allow the calculation of the relative pressures.

G5-13 50 C

The mass of nitrogen gas (M_r = 28·0) which must be mixed with 12 g of oxygen gas (M_r = 32·0) so that 5·6 dm^3 of the resulting gas mixture will contain equal numbers of molecules of each gas is

A $\frac{5\cdot6 \times 12 \times 28\cdot0}{22\cdot4 \times 32\cdot0}$ g.
B $\frac{22\cdot4 \times 12 \times 28\cdot0}{5\cdot6 \times 32\cdot0}$ g.
C $\frac{12 \times 28\cdot0}{32\cdot0}$ g.
D $\frac{12 \times 32\cdot0}{28\cdot0}$ g.

G5-14 70 D

Two vessels of equal volume contain helium gas (A_r = 4) and nitrogen gas (M_r = 28) respectively. The gas in each vessel is at the same temperature and pressure.
When the gases in the two vessels are mixed, the percentage by mass of nitrogen in the mixture is

A $\frac{4 \times 100}{28 + 4}$%. **B** $\frac{4 \times 100}{28}$%. **C** $\frac{14 \times 100}{14 + 4}$%. **D** $\frac{28 \times 100}{28 + 4}$%.

G5-15 40* D

Which one of the following samples of gas contains the **smallest** number of molecules?

A 1 dm^3 of carbon dioxide at 0 °C and 1×10^5 Pa
B 3 dm^3 of oxygen at 0 °C and 5×10^4 Pa
C 4 dm^3 of hydrogen at 546 °C and 1×10^5 Pa
D 5 dm^3 of nitrogen at 273 °C and 2×10^4 Pa

G5-16 60 D

The molar volume of a gas is 20 dm^3 at 400 K and 1.64×10^5 Pa pressure. What is the volume of 1.5 mol of the gas at 500 K and 1.64×10^5 Pa pressure?

A $\frac{20 \times 400 \times 1.5}{500}$ dm^3
B $\frac{20 \times 400}{1.5 \times 500}$ dm^3
C $\frac{1.5 \times 400}{20 \times 500}$ dm^3
D $\frac{20 \times 500 \times 1.5}{400}$ dm^3

G5-17 50 B

1.0 g of CO_2 (M_r = 44.0) occupies a volume of 400 cm^3. If 1.0 g of another gas occupies a volume of 550 cm^3 at the same temperature and pressure, the relative molecular mass of the gas is

A 28.0 **B** 32.0 **C** 40.8 **D** 60.5

G5-18 50 A

4.0 g of a gaseous oxide of nitrogen occupies a volume of 1.0 dm^3 at 546 K and 4.0 atm (4.0×10^5 Pa) pressure. The probable formula of the oxide is (given A_r: N = 14, O = 16; molar volume of a gas at STP = 22.4 dm^3 mol^{-1})

A N_2O. **B** NO. **C** N_2O_3. **D** N_2O_5.

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G5-19 40 D

If, at a fixed pressure, 2·20 g of a gas at 300 K occupies the same volume as 2·02 g of nitrogen gas at 290 K, then the molar mass of this gas is (given A_r N = 14)

A $\frac{2 \cdot 20 \times 14}{2 \cdot 02}$ g.

B $\frac{2 \times 2 \cdot 20 \times 14}{2 \cdot 02}$ g.

C $\frac{2 \cdot 20 \times 300 \times 14}{2 \cdot 02 \times 290}$ g.

D $\frac{2 \times 2 \cdot 20 \times 300 \times 14}{2 \cdot 02 \times 290}$ g.

E $\frac{2 \times 2 \cdot 20 \times 290 \times 14}{2 \cdot 02 \times 300}$ g.

G5-20 70 B

The exhaust gases from a six cylinder car which is idling contain 8% carbon monoxide by volume. What is the mass of carbon monoxide in 1 dm^3 of exhaust gas at STP (given A_r: C = 12, O = 16; molar volume of carbon monoxide at STP = 22.4 dm^3 mol^{-1})?

A 0.01 g B 0.1 g C 10 g D 100 g

G5-21 20 D

A person consumes 400 cm^3 of oxygen per minute at atmospheric pressure and 20 °C. The mass of oxygen (M_r = 32.0) consumed by the person in a minute is (given the molar volume of oxygen at STP = 22400 cm^3 mol^{-1})

A $\frac{293 \times 22400 \times 32.0}{273 \times 400}$ g.

B $\frac{293 \times 400 \times 32.0}{273 \times 22400}$ g.

C $\frac{273 \times 22400 \times 32.0}{293 \times 400}$ g.

D $\frac{273 \times 400 \times 32.0}{293 \times 22400}$ g.

G5-22 60 C

A man's lungs contain 6 dm^3 of air at 34 °C and 101 000 Pa pressure. The number of molecules of gas in his lungs is (given 1 atm = 101 000 Pa, $N_A = 6 \times 10^{23}$, molar volume of a gas at STP = 22.4 dm^3 mol^{-1})

A $\frac{101\,000 \times 6 \times 101\,000 \times 6 \times 10^{23}}{307 \times 273 \times 22.4}$.

B $\frac{6 \times 273 \times 22.4}{307 \times 6 \times 10^{23}}$.

C $\frac{6 \times 273 \times 6 \times 10^{23}}{307 \times 22.4}$.

D $\frac{307 \times 6 \times 10^{23}}{6 \times 273 \times 22.4}$.

G5-23 40 A

A balloon is inflated with 16.0 g of oxygen (M_r = 32.0) at 280 K. If the temperature rises to 320 K and the pressure remains constant, what mass of oxygen must be released from the balloon in order for the balloon to stay the same size?

A 2.0 g B 6.0 g C 10.0 g D 14.0 g E 18.3 g

G6 General gas equation

G6-1 80 A

A 5.0 dm^3 cylinder used for emergency medical treatment contains 130 g of oxygen gas. What is the gas pressure in the cylinder at 20 °C (given A_r O = 16.0, gas constant R = 8.31 J K^{-1} mol^{-1})?

A $\frac{130 \times 8.31 \times 293}{32.0 \times 5.0 \times 10^{-3}}$ Pa

B $\frac{32.0 \times 8.31 \times 293}{130 \times 5.0 \times 10^{-3}}$ Pa

C $\frac{130 \times 8.31 \times 293}{16.0 \times 5.0 \times 10^{-3}}$ Pa

D $\frac{130 \times 8.31 \times 20}{16.0 \times 5.0 \times 10^{-3}}$ Pa

G6-2 70 D

If a 5.0 dm^3 pressure cooker contained 0.30 mol of gas at 120 °C, the pressure in the cooker would be
(given the gas constant R = 8.31 J K^{-1} mol^{-1})

A $\frac{0.30 \times 8.31 \times 120}{5.0}$ Pa.

B $\frac{0.30 \times 8.31 \times 120}{5.0 \times 10^{-3}}$ Pa.

C $\frac{0.30 \times 8.31 \times 393}{5.0}$ Pa.

D $\frac{0.30 \times 8.31 \times 393}{5.0 \times 10^{-3}}$ Pa.

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G6-3 70 **D**

What is the molar mass of a gas if 0.20 g of the gas occupies 2.45 dm^3 at 1.0×10^5 Pa and 25 °C (given the gas constant, R = 8.31 J K^{-1} mol^{-1})?

A $\frac{8.31 \times 298}{0.20 \times 1.0 \times 10^5 \times 2.45 \times 10^{-3}}$ g mol^{-1}

B $\frac{0.20 \times 1.0 \times 10^5 \times 2.45 \times 10^{-3}}{8.31 \times 298}$ g mol^{-1}

C $\frac{0.20 \times 8.31 \times 298 \times 6.0 \times 10^{23}}{1.0 \times 10^5 \times 2.45 \times 10^{-3}}$ g mol^{-1}

D $\frac{0.20 \times 8.31 \times 298}{1.0 \times 10^5 \times 2.45 \times 10^{-3}}$ g mol^{-1}

The next three items refer to the following information

Nitrogen gas for commercial or laboratory use is usually stored in gas cylinders. A particular cylinder contains 5 dm^3 of nitrogen (M_r = 28.0) at a pressure of 2000 kPa at 20 °C.

The gas constant, R, is 8.31 J K^{-1} mol^{-1} and 1 kPa = 10^3 Pa.

G6-4 70 **C**

The volume of the gas at 20 °C and at the room pressure (100 kPa) would be

A 0.25 dm^3. **B** 10 dm^3. **C** 100 dm^3. **D** 500 dm^3.

G6-5 70 **B**

The pressure of the gas in the cylinder at 40 °C would be

A 2×2000 kPa.

B $\frac{2000 \times 313}{293}$ kPa.

C $\frac{2000 \times 293}{313}$ kPa.

D $\frac{1}{2} \times 2000$ kPa.

G6-6 70* **D**

The mass of nitrogen in the cylinder is

A $\frac{8.31 \times 293 \times 28.0}{2000 \times 10^3 \times 5 \times 10^{-3}}$ g.

B $\frac{2000 \times 10^3 \times 5 \times 10^{-3}}{8.31 \times 293}$ g.

C $\frac{2000 \times 10^3 \times 8.31}{5 \times 10^{-3} \times 293 \times 28.0}$ g.

D $\frac{2000 \times 10^3 \times 5 \times 10^{-3} \times 28.0}{8.31 \times 293}$ g.

G7 Density

G7-1 60 **D**

If samples of two different gases have the same density, then the

A samples must be at the same temperature and pressure.
B gases must have the same relative molecular mass.
C pressures of the two gases must be equal.
D masses of equal volumes of the two samples must be the same.

G7-2 40 **C**

A certain gas is twice as dense as oxygen gas, both gases being at the same temperature and pressure. The relative molecular mass of the gas is (given A_r O = 16)

A $\frac{2}{1 \times 16}$.

B $\frac{2 \times 16}{2}$.

C $2 \times 2 \times 16$.

D 2×16.

G7-3 40 **A**

A gas has a relative molecular mass of 28.0, and a density of 1.25 g dm^{-3} at STP. The molar volume of this gas at STP is (in dm^3 mol^{-1})

A $\frac{28.0}{1.25}$. **B** $\frac{1.25}{28.0}$. **C** $\frac{28.0}{1.25} \times \frac{22.4}{1}$. **D** $\frac{1.25}{28.0} \times \frac{1000}{1}$.

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G7-4 80 C | The measured density at STP of helium gas is 0.1784 g dm^{-3}. The mass (in gram) of one mole of He atoms is therefore (A_r He = 4.00)

A $\frac{0.1784}{4.00}$. B 0.1784 × 4.00. C 0.1784 × 22.4. D $\frac{0.1784}{22.4}$.

G7-5 30 B | The density of a sample of carbon dioxide gas is measured at 15 °C and 1.014×10^5 Pa pressure. If the pressure is reduced to 0.507×10^5 Pa and the temperature increased to 30 °C, the density will

A be increased four-fold.
B be decreased.
C be doubled.
D remain unchanged.

G8 Partial pressures

G8-1 70 C | A gaseous mixture contains 1 mol of hydrogen molecules, 4 mol of nitrogen molecules and 3 mol of ammonia molecules under a total pressure of 2×10^7 Pa. What is the partial pressure of ammonia, in Pa, in the mixture?

A 1.25×10^6 B 3.75×10^6 C 7.5×10^6 D 6×10^7

The next three items refer to the following information

An industrial plant uses ethene gas and propene gas for the manufacture of plastics. The ethene is stored in a 200 m^3 tank (tank A) at a pressure of 3×10^5 Pa and the propene is stored in a 300 m^3 tank (tank B) at a pressure of 4×10^5 Pa. Both vessels are at the same temperature.

The gases in the tanks can be mixed without a reaction occuring.

G8-2 70 C | The ratio of the number of molecules of ethene in tank A to the number of molecules of propene in tank B is

A 2:3. B 3:4. C 1:2. D 2:1.

G8-3 40 A | If both gases were pumped into tank B, and the original temperature restored, the new pressure in B is

A 6×10^5 Pa. B 7×10^5 Pa. C 9×10^5 Pa. D 1.8×10^6 Pa.

G8-4 60 A | If tanks A and B were connected and the system allowed to come to equilibrium at the original temperature, the pressure would be

A 3.6×10^5 Pa. B 3.0×10^5 Pa. C 2.8×10^5 Pa. D 1.4×10^5 Pa.

G8-5 30 D | The pressure gauge on a 5 dm^3 oxygen cylinder used for emergency medical treatment reads 2.00×10^6 Pa at 20 °C. If 20 dm^3 of oxygen, measured at 20 °C and 1.00×10^5 Pa, were used during an emergency, the pressure gauge would read

A 0 Pa.
B 4.0×10^5 Pa.
C 1.00×10^6 Pa.
D 1.60×10^6 Pa.
E 1.90×10^6 Pa.

The next three items refer to the following information

A vessel containing 20.0 dm^3 of argon (A_r = 40) at a pressure of 1.00×10^5 Pa is connected to another vessel containing 30.0 dm^3 of helium (A_r = 4) at a pressure of 2.00×10^5 Pa. A valve between the two is opened and the two gases mix at constant temperature.

G8-6 20 C | The resulting pressure of the gas mixture will be

A 1.20×10^5 Pa.
B 1.50×10^5 Pa.
C 1.60×10^5 Pa.
D 1.80×10^5 Pa.
E 3.00×10^5 Pa.

G8-7 50 C | The value of the fraction, $\frac{\text{original helium concentration (M)}}{\text{final helium concentration (M)}}$, is

A $\frac{5}{2}$. B $\frac{5}{1}$. C $\frac{5}{3}$. D $\frac{3}{1}$.

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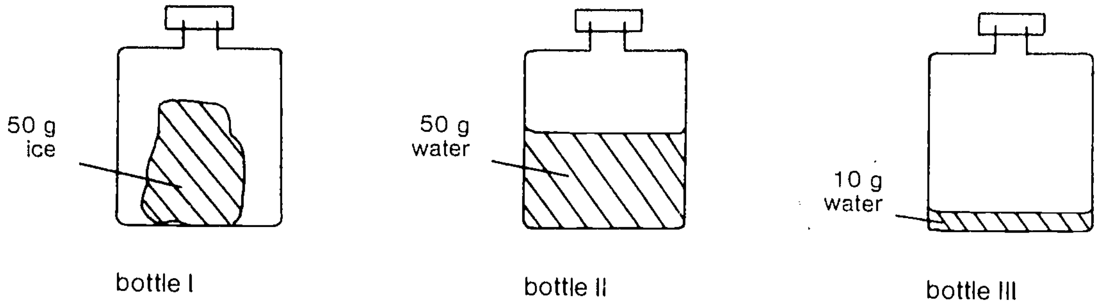
G8-8 30 C

Compared to the original sample of helium, the mixture would have

A the same distribution of molecular velocities.
B the same average molecular velocity.
C a lower average molecular velocity.
D a higher minimum molecular velocity.

G9 Vapour pressure

G9-1 30 C



The diagram shows three sealed bottles which have been kept at 0 °C for some time. Which one of the following statements about them is correct?

A In bottle I there are no water molecules in the space above the ice.
B In bottle II there are no water molecules entering or leaving the water.
C In bottle III there will be the same number of molecules of water vapour per unit volume as in bottle II.
D In bottle III there will be fewer molecules of water vapour per unit volume than in bottle II.
E In bottle III the average kinetic energy of the molecules is one-fifth of that in bottle II.

G9-2 80 C

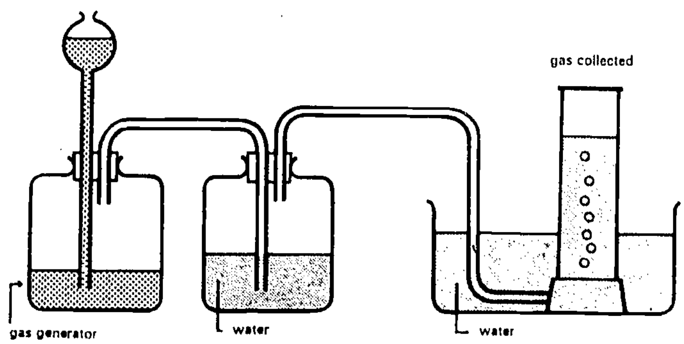
The vapour pressure of a liquid is observed to increase with increase of temperature. Which of the following statements best explains this increase?

At higher temperatures

A the faster-moving molecules in the liquid exert a greater pressure.
B every molecule has greater kinetic energy.
C the average kinetic energy of molecules is greater, thus enabling more molecules to enter the vapour state.
D the number of gaseous molecules above the liquid remains constant but these molecules have greater average kinetic energy.

G9-3 70 B

Hydrogen gas is produced, using the apparatus shown.



200 cm^3 of gas is collected at 1.035×10^5 Pa pressure and 15 °C.

What is the partial pressure of hydrogen (saturated water vapour pressure at 15 °C is 0.017×10^5 Pa)?

A 1.035×10^5 Pa
B 1.018×10^5 Pa
C 1.0205×10^5 Pa
D 0.0170×10^5 Pa

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G9-4 60* C | Dry air at a pressure of 1.0×10^5 Pa has a partial pressure of oxygen of 2.1×10^4 Pa. Assuming air to be composed only of nitrogen and oxygen, what would be the percentage by mass of oxygen in dry air (given A_r: O = 16, N = 14)?

A $\frac{2.1 \times 32 \times 100}{7.9 \times 28}$

B $\frac{2.1 \times 32 \times 100}{10}$

C $\frac{2.1 \times 32 \times 100}{(2.1 \times 32) + (7.9 \times 28)}$

D $\frac{2.1 \times 10^4 \times 32 \times 100}{22.4 \times 28}$

G9-5 30 E | Marsh gas is often produced at the bottom of stagnant lakes by the decomposition of organic material. A 100 cm^3 sample of marsh gas was collected as it bubbled to the surface. The water temperature was 18 °C and atmospheric pressure was 98.0 kPa.

What would be the volume of the marsh gas if dry and at 24 °C and 102.0 kPa?

(The saturated water vapour pressures at 18 °C and 24 °C are, respectively 2.0 kPa and 3.0 kPa.)

A $\frac{98.0 \times 100 \times 297}{291 \times 103.0} cm^3$

B $\frac{98.0 \times 100 \times 297}{291 \times 99.0} cm^3$

C $\frac{100.0 \times 100 \times 297}{291 \times 102.0} cm^3$

D $\frac{96.0 \times 100 \times 297}{291 \times 99.0} cm^3$

E $\frac{96.0 \times 100 \times 297}{291 \times 102.0} cm^3$

G9-6 20 C | A cylinder contains oxygen gas and a small amount of liquid water at a temperature of 18 °C. The vapour pressure of water in the cylinder is 2.0×10^3 Pa and the total pressure is 4.0×10^4 Pa. A piston is then pushed into the cylinder until the volume is reduced to one third of its original value. If the temperature remains constant the final total pressure will be

A 1.30×10^4 Pa.

B 1.12×10^5 Pa.

C 1.16×10^5 Pa.

D 1.20×10^5 Pa.

G9-7 60* B | A large amount of mercury was spilled in a 2×10^5 dm^3 laboratory. If the temperature of the laboratory was 20 °C and the saturated vapour pressure of mercury at this temperature is 0.27 Pa, what would be the concentration of mercury in the air in the laboratory when equilibrium was attained?

(The gas constant $R = 8.31$ J K^{-1} mol^{-1})

A $\frac{0.27 \times 8.31}{293 \times 2 \times 10^5}$ mol dm^{-3}

B $\frac{0.27 \times 10^{-3}}{8.31 \times 293}$ mol dm^{-3}

C $\frac{0.27 \times 293 \times 10^{-3}}{8.31 \times 2 \times 10^5}$ mol dm^{-3}

D $\frac{8.31 \times 293}{0.27 \times 10^{-3}}$ mol dm^{-3}

G10 Boiling

G10-1 50* B | Water boils at 100 °C at sea level. On top of Mount Kosciusko it boils at about 93 °C. Which of the following statements gives the best reason for this difference?

A The lower atmospheric pressure lowers the vapour pressure of the water.

B The vapour pressure of the water reaches atmospheric pressure at a lower temperature.

C The drier air on the top of the mountain can accept more water vapour.

D Molecules of water move faster when the pressure is reduced and so escape more easily.

G10-2 50 B | When water is boiled in a pressure cooker, the valve in the cooker releases the water vapour when the internal pressure exceeds a certain value. The temperature of the boiling water when the water vapour begins to be released would be

A less than 100 °C. B more than 100 °C. C equal to 100 °C.

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G10-3 30 **D**

Water begins to boil when

A its vapour pressure is greater than the vapour pressure of water in the atmosphere.

B the average kinetic energy of the vapour particles is greater than the average kinetic energy of the water particles.

C the velocity of some molecules becomes high enough to escape from the water surface.

D its vapour pressure is equal to the atmospheric pressure.

G10-4 40 **B**

Four different liquids are kept at different temperatures while the pressure on them is slowly reduced by a single vacuum pump. Given the data below, which liquid should boil first?

Liquid	Temperature /°C	Vapour pressure at the specified temperature /Pa
I	20	0.97×10^4
II	25	1.50×10^4
III	35	1.37×10^4
IV	50	1.22×10^4

A I **B** II **C** III **D** IV

G11 Non-ideal gases

G11-1 60 **A,B**

At high pressure, gases do not behave as predicted by Boyle's law (PV = constant). This is because it cannot be assumed that at high pressures

A the volume occupied by the molecules compared with the total volume of the gas is negligible.

B there are no attractive forces between the molecules themselves.

C the molecules are in a state of rapid motion.

D molecules collide with the wall of the container.

(There is more than one correct answer to this question)

G11-2 30 **B**

The postulates of the kinetic theory of gases may be stated briefly:

(i) gas molecules move rapidly in random directions;

(ii) the absolute temperature of a gas is dependent on the average kinetic energy of the molecules;

(iii) the size of a gas molecule is insignificant in comparison with the volume in which it moves;

(iv) there are no attractive or repulsive forces between the molecules.

Three of these postulates become invalid as the temperature of a real gas approaches the liquefaction temperature. Which one of them remains true for a real gas at all temperatures?

A (i) **B** (ii) **C** (iii) **D** (iv)

G11-3 20 **C**

The behaviour of a real gas is most likely to approach the behaviour of an ideal gas

A only at the absolute zero of temperature.

B when the temperature is decreased and pressure is increased.

C when the temperature is increased and the pressure is decreased.

D when both temperature and pressure are increased.

E when both temperature and pressure are decreased.

G11-4 50 **B**

For any gas, we may define the deviation from ideal molar volume, d, as the magnitude of the difference between the actual molar volume of the gas and the ideal gas molar volume (22.414 dm^3 at STP).

Which one of the following gases would have the greatest value of d?

A nitrogen which has a boiling point of 77 K

B carbon dioxide which sublimes at 194 K

C helium which is a noble, chemically inert gas

D hydrogen which liquefies at 20 K

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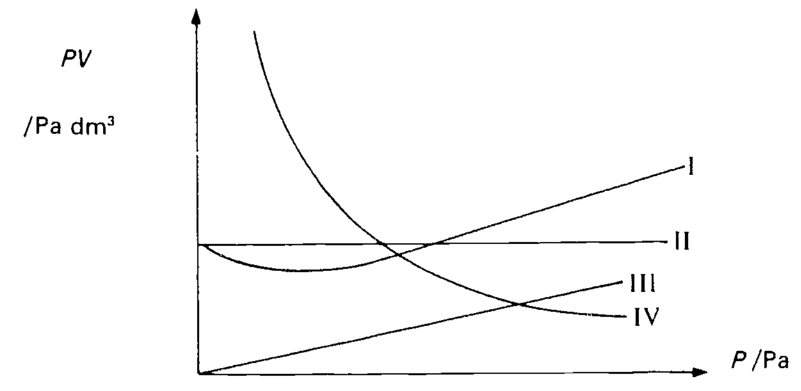

One of the above curves represents the way the product of pressure and volume (PV) varies with pressure (P) for an ideal gas. Another curve represents a possible relationship for a real gas. The other two curves do not describe the behaviour of any currently known gas.

G11-5 50* **B**

Which curve represents the ideal gas?

A I **B** II **C** III **D** IV

G11-6 50 **A**

Which curve represents the real gas?

A I **B** II **C** III **D** IV

G11-7 10* **B**

Under which one of the following sets of conditions is hydrogen closest to behaving as an ideal gas?

A pressure = 3.8×10^4 Pa, temperature = 25 °C
B pressure = 3.8×10^4 Pa, temperature = 100 °C
C pressure = 1.0×10^5 Pa, temperature = 25 °C
D pressure = 1.0×10^5 Pa, temperature = 100 °C

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H SOLUTIONS

H1 Dissociation

H1-1
40
B

Which one of the following statements concerning the solute particles in a potassium chloride solution is correct?

A The particles will eventually settle to the bottom of the solution.
B A beam of light directed through the solution would not be scattered by the particles.
C Addition of an electrolyte to the solution will cause the particles to clump together.
D The particles can be filtered from the liquid using a fine grained filter paper.

H1-2
60
E

The species present in largest number in a solution of magnesium sulfate are

A magnesium sulfate molecules and water molecules.
B magnesium ions, sulfate ions, hydrogen ions and hydroxide ions.
C magnesium atoms, sulfur atoms, oxygen atoms and hydrogen atoms.
D magnesium atoms, sulfur atoms, oxygen atoms and water molecules.
E magnesium ions, sulfate ions and water molecules.

H1-3
60
A

If a solution of $MgCl_2$ contains 2×10^{23} anions, the number of cations in the solution will be

A 1×10^{23}. B 2×10^{23}. C 4×10^{23}. D 6×10^{23}.

H1-4
60*
D

Sodium uranyl perchlorate $NaUO_2(ClO_4)_3$ is soluble in water, dissolving to form the species Na^+, UO_2^{2+}, and ClO_4^- in solution. When 0.1 mol of this compound is dissolved in 1 dm^3 of water, the relative concentrations of Na^+, UO_2^{2+} and ClO_4^- are respectively

A 1:1:1. B 1:2:1. C 1:2:3. D 1:1:3. E 3:1:1.

H2 Ionization

H2-1
50
D

Hydrogen bromide gas was dissolved in benzene and the resulting solution was poured onto lumps of calcium carbonate. There was no apparent change. Then some water was added. Carbon dioxide gas began to be evolved.

This is because the hydrogen bromide became ionized in the

A benzene, and then acid-catalysed hydrolysis of the benzene formed the carbon dioxide.
B water, and then this ionized solution reacted with the benzene forming the carbon dioxide.
C benzene, and the calcium carbonate ionized in the water and then these two solutions reacted forming the carbon dioxide.
D water, and then this ionized solution reacted with the calcium carbonate forming the carbon dioxide.
E benzene, and formed bromobenzene which was dehydrated by the calcium carbonate to form the carbon dioxide.

H3 Conductivity of electrolytes

H3-1
40
D

Aqueous solutions of sodium chloride are good conductors of electricity. This is a result of the movement **in solution** of

A electrons only.
B cations only.
C anions only.
D cations and anions only.
E electrons, cations and anions.

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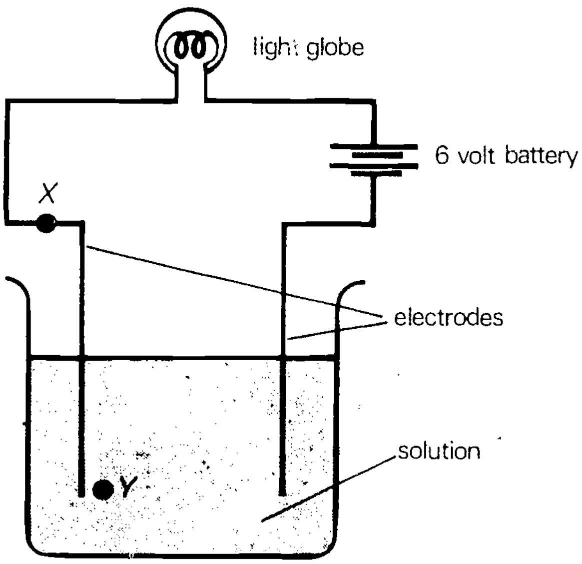
H3-2 70 D

A solid dissolves in a liquid to form a solution which conducts electricity. The only conclusion that can be drawn from this information is that the

A solution contains free or mobile electrons.
B original solid contained free or mobile electrons.
C original solid contained ions.
D solution contains free or mobile ions.

The next two items refer to the diagram below:



H3-3 60 A

When the liquid in the beaker is distilled water, and hydrogen chloride gas is bubbled through it, the globe begins to glow brightly. If the distilled water is replaced with toluene, and hydrogen chloride gas is bubbled through it, the globe does not light. These observations are best explained by proposing that

A hydrogen chloride gas dissolves in water to form charged particles, whereas in toluene it remains as neutral particles.
B the concentration of hydrogen chloride molecules in the water is greater than the concentration of hydrogen chloride molecules in the toluene.
C distilled water is a good conductor of electricity, whereas toluene is a poor conductor of electricity.
D electrons are able to flow through water when hydrogen chloride gas is added to it but not through toluene which has hydrogen chloride gas added to it.

H3-4 70 D

When an ionic solution is placed in the beaker, a current flows through the circuit and the light glows brightly. Which one of the following statements best describes how this current is moving at points *Y* and *X*?

A There are freely moving ions at both *X* and *Y*.
B Electrons flow through the solution at *Y* and through the wire at *X*.
C Vibrating ions in the solution at *Y* transmit electricity to the wire, which is carried at *X* by vibrating metal atoms.
D At *Y* there are freely moving charged ions, while at *X* electrons move freely in the wire.

H3-5 80 D

Solutions of copper(II) sulfate are good conductors of electricity because the solution contains

A electrons which are free to move.
B water which is a good conductor.
C copper which is a good conductor.
D ions which are free to move.

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H3-6 50* B | Which one of the following solutions is the best conductor of electricity?

A 1.5 M ethanoic (acetic) acid solution
B 1.0 M potassium chloride solution
C 2.0 M ammonia solution
D 0.5 M magnesium chloride solution

H4 Saturation

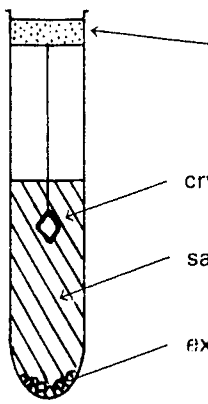
H4-1 60* B | Which one of the following terms most accurately describes the liquid which remains when hot brine is cooled down until crystals of salt appear?

A solute
B saturated solution
C solvent
D unsaturated solution

H4-2 60 B | In a saturated solution of sodium chloride the sodium chloride particles are

A leaving the crystals at a faster rate than they are returning to them.
B leaving the crystals at the same rate at which they are returning to them.
C returning to the crystals at a faster rate than they are leaving them.
D neither leaving the crystals nor returning to them.

H4-3 30* C | A crystal of solute was suspended in a stoppered flask filled with a saturated solution, as shown.



The size of the crystal would be expected to

A increase.
B decrease.
C remain unchanged.

H4-4 20 C | Which one of the following best describes a saturated solution?

A A saturated solution contains a small amount of solute in a large volume of solvent.
B A saturated solution is one in which the addition of further solvent produces a precipitate.
C A saturated solution is one in which crystals of the solute can stand without dissolving or growing.
D A saturated solution contains a very large amount of solute in a small volume of solvent.

H4-5 20* A | Saturation of a solution is achieved more quickly if the solute is stirred with the solvent. Which one of the following is the best explanation of this fact?

A Stirring reduces the number of solute particles in solution near the crystals.
B Stirring cools the solution and less solute is required to produce a saturated solution.
C A moving solution requires fewer particles in solution for it to be saturated than does a stationary solution.
D Stirring raises the kinetic energy of the solute particles, allowing them to escape from the crystal surfaces more rapidly.

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H5 Solubility

H5-1 20 C

If 3.2 g of salt forms 12.2 g of saturated solution at a certain temperature, what is the solubility of salt in g per 100 g of water at that temperature?

A $3.2 \times \frac{100}{12.2}$

B $12.2 \times \frac{100}{3.2}$

C $3.2 \times \frac{100}{(12.2 - 3.2)}$

D $3.2 \times \frac{(12.2 - 3.2)}{100}$

H5-2 80 A

The solubility of potassium chloride is 40 g per 100 g of water at 50 °C. 10 g of potassium chloride was added to a beaker containing 20 g of water at 50 °C and stirred until the solution was saturated. The mass of undissolved potassium chloride at 50 °C was

A 2 g. **B** 4 g. **C** 6 g. **D** 10 g.

The next three items refer to the following table

	0 °	20 °	40 °	60 °	80 °	100 °C
solubility of KNO_3 (g/100 g of water)	13.3	31.6	64.0	110	169	246
solubility of NaCl (g/100 g of water)	35.7	35.9	36.5	37.2	38.0	39.1

H5-3 40 A

42.0 g of KNO_3 was dissolved in 100 g of boiling water and the solution was cooled to 20 °C. The mass of crystals formed would be

A 10.4 g. **B** 13.3 g. **C** 31.6 g. **D** 42.0 g.

H5-4 60 B

To what temperature must 5.0 g of water be heated so that it just dissolves 5.5 g of KNO_3?

A 40 °C **B** 60 °C **C** 80 °C **D** 100 °C

H5-5 50 B

What is the minimum mass of boiling water required to dissolve 7.82 g of NaCl?

A 10 g **B** 20 g **C** 50 g **D** 100 g **E** 195.5 g

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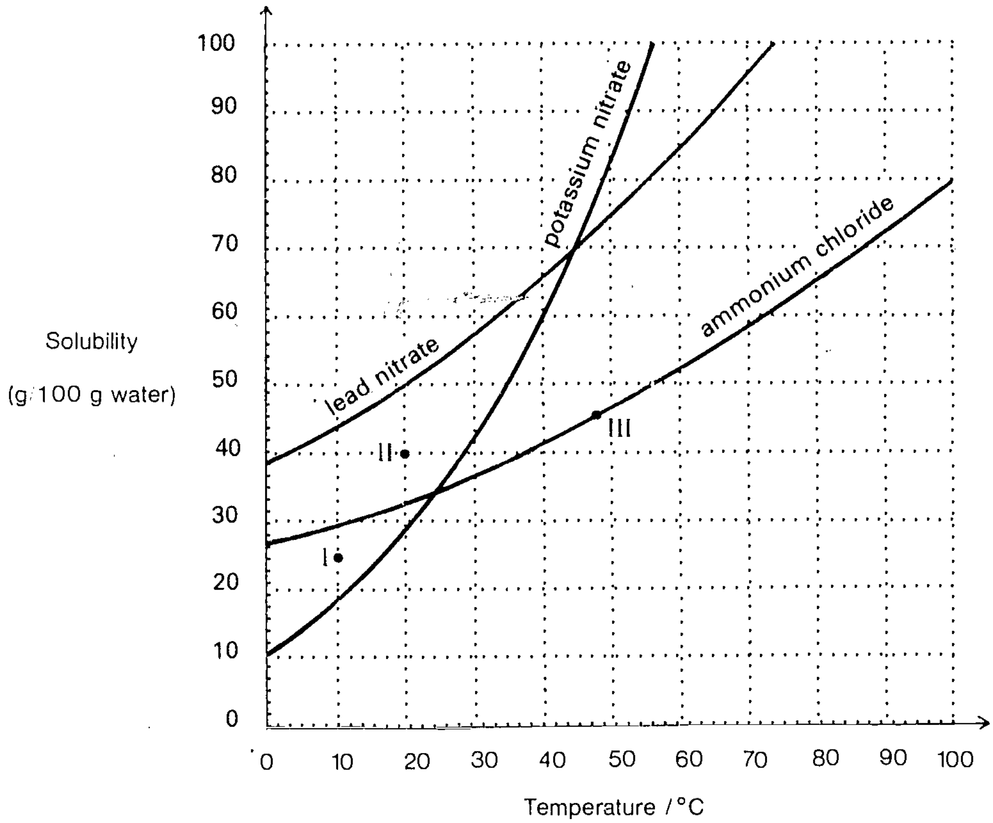
The next three items refer to the following information

The graph below shows the solubilities of three different substances in water over a range of temperatures.



H5-6 To completely dissolve 15 g of lead nitrate in 30 g of water the temperature would have to be at least
80
A

A 20 °C. B 30 °C. C 40 °C. D 50 °C.

H5-7 Points I, II and III on the graph represent three solutions of ammonium chloride. Which point represents
60 a supersaturated solution?
B

A I B II C III

H5-8 15 g of potassium nitrate was dissolved in 25 g of boiling water. If the solution were slowly cooled,
70 the first crystals of potassium nitrate would be expected to appear at
B

A 3 °C. B 40 °C. C 56 °C. D 68 °C.

H5-9 The solubility of potassium chloride is 40 g per 100 g of water at 50 °C. 100 g of potassium chloride
70 is added to a beaker containing 100 g of water at 50 °C.
C

How much more water will have to be added to dissolve the excess potassium chloride if the temperature is maintained at 50 °C?

A 60 g B 100 g C 150 g D 250 g

H5-10 The solubility of potassium nitrate is
60 30 g per 100 g of water at 20 °C;
A 80 g per 100 g of water at 50 °C.

If 100 g of potassium nitrate is added to a beaker containing 20 g of water at 20 °C, some will dissolve. How much **more** potassium nitrate will dissolve if the temperature is raised to 50 °C?

A 10 g B 18 g C 50 g D 60 g

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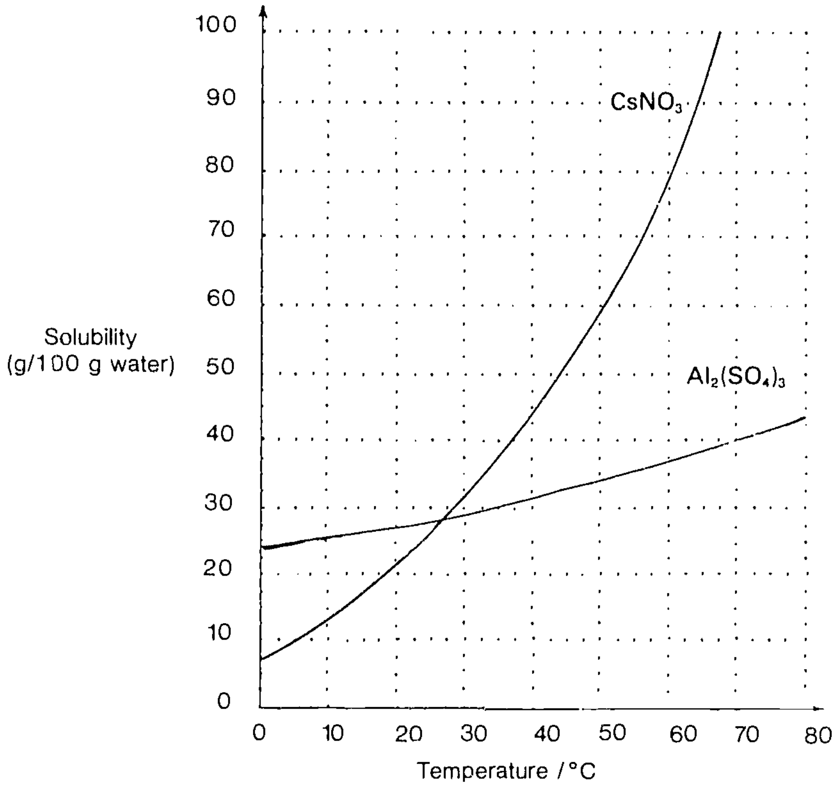
The next three items refer to the following information:

The solubility curves below show the variation in solubility of some salts in water with change in temperature.



H5-11 50 **B**

At which of the following temperatures is a saturated solution of caesium nitrate likely to be formed when 40.0 g of caesium nitrate is added to 50 g of water?

A 50 °C only
B both 50 °C and 60 °C
C all of 50 °C, 60 °C, and 70 °C
D all of 50 °C, 60 °C, 70 °C, and 80 °C

H5-12 40* **A**

10 g of aluminium sulfate is present in 50 g of water at 35 °C. To make the solution saturated at this temperature, more solid needs to be added. Which one of the following masses is most nearly the amount required?

A 5 g **B** 10 g **C** 15 g **D** 20 g

H5-13 50 **C**

70.0 g of caesium nitrate is shaken with 100 g of water at 45 °C. After a long time the temperature is lowered to 10 °C. As the temperature is lowered the caesium nitrate particles would be expected to

A leave the crystals at a faster rate than they return to them.
B leave the crystals at the same rate at which they return to them.
C return to the crystals at a faster rate than they leave them.
D neither leave the crystals nor return to them.

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H6 Factors affecting solubility

H6-1 80 D

Paraffin wax is a mixture of high-molecular-mass alkanes which is often used as a waterproofing agent because of its water repellent properties and its insolubility in water. It is applied to fabrics dissolved in the solvent 'Shellite'.

From this information, it is reasonable to infer that 'Shellite'

A is soluble in water.

B has a higher relative molecular mass than water.

C is more volatile than water.

D is a non-polar solvent.

H6-2 60 D

Solutions of the following were mixed. In which case would a precipitate be **least** likely to form?

A $CaCl_2$ and Na_2CO_3

B $AlCl_3$ and $NaOH$

C $AgNO_3$ and $NaCl$

D $MgCl_2$ and KNO_3

H6-3 30* A

Excess solid AgCl is placed in each of the following solutions. In which will the **least** amount of solid dissolve?

A 0.01 M Ag_2SO_4

B 0.01 M $AgNO_3$

C 0.01 M HCl

D 0.01 M NH_3

H7 Concentration (molarity)

H7-1 40 B

Sodium fluoride is added to a town water storage to give a **fluoride ion** concentration of one kilogram of fluoride ion per megalitre of water. What mass of **sodium fluoride**, NaF, should be added to a storage of 250 megalitres of water?

(1 megalitre = 10^6 dm^3; A_r : Na = 23, F = 19)

A $\frac{250 \times 19}{23 + 19}$ kg

B $\frac{(23 + 19) \times 250}{19}$ kg

C $\frac{(23 + 19) \times 250}{10^3}$ kg

D $\frac{(23 + 19) \times 10^3}{250 \times 19}$ kg

E $\frac{(23 + 19) \times 19}{250}$ kg

H7-2 40 B

In order to prepare a standard 0·100 M solution of sodium carbonate (M_r = 106), 10·6 g of anhydrous sodium carbonate should be dissolved in

A 1000 cm^3 of water.

B enough water to make 1000 cm^3 of solution.

C 1000 g of water.

D enough water to make 1000 g of solution.

H7-3 60 D

A NaOH solution contains 0.019 mol of OH^- per dm^3. The concentration of the NaOH solution is exactly (M_r : NaOH = 40, OH^- = 17)

A $\frac{0.019}{17} \times 40$ M.

B 2×0.019 M.

C $\frac{0.019 \times 17}{40}$ M.

D 0.019 M.

H7-4 90 D

2.00 g of sodium hydroxide (NaOH) was dissolved in a little water and then more water was added to make a total volume of 50 cm^3. What is the concentration of this solution? (M_r NaOH = 40)

A 0.05 M **B** 0.10 M **C** 0.50 M **D** 1.00 M

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H7-5
30
E

The concentration of NO_3^- ions in 500 cm^3 of 0.30 M $Al(NO_3)_3$ solution is

A 0.10 M. **B** 0.30 M. **C** 0.45 M. **D** 0.60 M. **E** 0.90 M.

H7-6
20
B

100 cm^3 of a solution of iron(III) sulfate in water is prepared from 2.81 g of $Fe_2(SO_4)_3.9H_2O$. What is the concentration of this solution with respect to Fe^{3+} ions? (M_r: $Fe_2(SO_4)_3$ = 400, H_2O = 18)

A 0.15 M **B** 0.10 M **C** 0.050 M **D** 0.025 M **E** 0.0167 M

H7-7
60
B

The NaCl concentration in a sample of sea water is 0.5 M. If 2.0 m^3 of the sea water were evaporated to dryness, the mass of salt remaining would be (given M_r NaCl = 58.5)

A $\frac{0.5 \times 58.5}{2.0 \times 10^3}$ g.

B $0.5 \times 2.0 \times 10^3 \times 58.5$ g.

C $\frac{0.5 \times 58.5}{2.0}$ g.

D $0.5 \times 2.0 \times 58.5$ g.

H7-8
50
D

The mass of anhydrous sodium carbonate required to make up exactly 2 dm^3 of 0·025 M solution is (A_r Na = 23; C = 12; O = 16)

A $2 \times 0{\cdot}025 \times (23 + 12 + [3 \times 16])$ g.

B $\frac{0{\cdot}025 \times (23 + 12 + [3 \times 16])}{2}$ g.

C $\frac{2 \times 0{\cdot}025}{(23 + 12 + [3 \times 16])}$ g.

D $2 \times 0{\cdot}025 \times ([2 \times 23] + 12 + [3 \times 16])$ g.

E $\frac{0{\cdot}025 \times ([2 \times 23] + 12 + [3 \times 16])}{2}$ g.

H7-9
20
A

The mass of $MgCl_2$ (M_r = 59.8) required to prepare 100 cm^3 of a solution which has a chloride ion concentration of 0.0100 M is

A 0.0299 g. **B** 0.0598 g. **C** 0.1196 g. **D** 0.598 g.

H7-10
30
D

Solutions of ammonium nitrate, NH_4NO_3, are often applied to gardens to act as a source of nitrogen for plants. The mass of nitrogen present in 8 dm^3 of a 0.2 M NH_4NO_3 solution is (given M_r NH_4NO_3 = 80; A_r N = 14)

A $\frac{0.2 \times 8 \times 14 \times 2}{80}$ g.

B $\frac{0.2 \times 8 \times 80}{14 \times 2}$ g.

C $0.2 \times 8 \times 14$ g.

D $0.2 \times 8 \times 14 \times 2$ g.

H7-11
30
D

Which of the following solutions contains the greatest mass of NaCl (M_r = 58.5)?

(The densities of the solutions may be assumed to be approximately 1 g cm^{-3}.)

A 2 dm^3 of a 0.1 M NaCl solution
B 1 dm^3 of a solution containing 30 g dm^{-3} NaCl
C 6 dm^3 of a solution containing 0.1 g NaCl per 100 g of solution
D 2 dm^3 of a solution containing 3% NaCl by mass

H7-12
50
A

A brand of beer has an ethanol concentration of 1.20 M. An unscrupulous hotel keeper serves drinks made by mixing one barrel of the beer with three barrels of water. The concentration of ethanol in the drinks would be about

A 0.30 M. **B** 0.40 M. **C** 1.20 M. **D** 3.60 M.

H7-13
30
C

30 cm^3 of 0.1 M aluminium perchlorate, $Al(ClO_4)_3$, is made up to a total volume of 100 cm^3 with water. The concentration of perchlorate ions in the resulting solution would be

A 0.1 × (30/100) M.
B 0.3 M.
C 0.3 × (30/100) M.
D 0.03 M.
E 0.3 × (30/130) M.

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H7-14 50 A

250 cm^3 of 0.2 M HCl solution is to be made by diluting the concentrated reagent which is 11.7 M. The volume of the concentrated reagent required is

A $\frac{250 \times 0.2}{11.7}$ cm^3.

B $\frac{250 \times 0.2}{1000 \times 11.7}$ cm^3.

C $\frac{1000 \times 0.2}{250 \times 11.7}$ cm^3.

D $\frac{11.7}{0.25 \times 0.2}$ cm^3.

H7-15 30 C

In order to dilute 20 cm^3 of 0.6 M H_2SO_4 to 0.1 M, the volume of water which would be needed to be added would be

A 40 cm^3. B 60 cm^3. C 100 cm^3. D 120 cm^3.

H7-16 50 C

The following solutions are mixed:
20 cm^3 0.2 M NaCl, 40 cm^3 0.1 M $MgCl_2$ and 40 cm^3 0.2 M $AlCl_3$.

After thorough mixing an accident occurs and half of the mixture is lost. The concentration of chloride ion in the remaining solution is

A 0.16 M. B 0.18 M. C 0.36 M. D 0.72 M.

H7-17 50 D

Pure water has a density of 1.0 g cm^{-3}. The concentration of H_2O (M_r = 18) in pure water is given by

A $\frac{1.0}{18}$ M.

B $18 \times 1.0 \times 10^3$ M.

C $\frac{18}{1.0 \times 10^3}$ M.

D $\frac{1.0 \times 10^3}{18}$ M.

H7-18 60* A

A brand of beer contains 5% by mass of ethanol. If the density of beer is 1.0 g cm^{-3}, the concentration of ethanol in beer, in mol dm^{-3}, is (given M_r C_2H_5OH = 46)

A $\frac{5 \times 1000}{100 \times 46}$.

B $\frac{5 \times 1000}{95 \times 46}$.

C $\frac{5}{100 \times 46}$.

D $\frac{5 \times 1000}{100 \times 46 \times 95}$.

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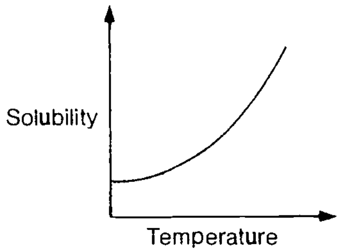
H8 Solubility of gases in liquids

H8-1 20 **D**

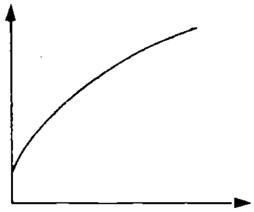
The ability of carbon dioxide gas to dissolve in water is used to prepare carbonated drinks.

Which one of the following graphs best represents the relationship between the solubility of carbon dioxide in water and the temperature of the solution?

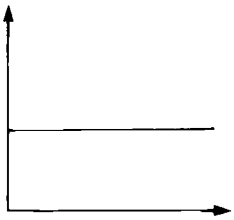
A



C



B



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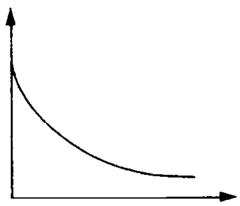

H8-2 50 **C**

Which one of the following sets of conditions during manufacture would lead to the most concentrated solution of carbon dioxide in soft drink?

A high temperature and high pressure

B high temperature and low pressure

C low temperature and high pressure

D low temperature and low pressure

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I SURFACES

I1 Interfaces

I1-1
90
A

Which of the following is **not** an example of a simple interface?

A gas–gas
B gas–liquid
C solid–solid
D liquid–liquid

I1-2
90
C

Which of the following processes or phenomena is **not** associated with a liquid–gas interface?

A foams
B froths
C emulsions
D distillation

I2 Suspensions, Colloids

I2-1
60*
B

The solid particles present in a suspension

A will not scatter the light of an incident light beam.
B can be filtered from the liquid.
C are smaller than those in a colloid.
D will not settle out as a sediment.

I2-2
50
A

A liquid scatters some of the light of an incident light beam. When the liquid is filtered, the filtrate obtained does not scatter light.

On the basis of this information alone, the liquid is best described as a

A suspension.
B colloid.
C solution.
D solute.

I2-3
30
D

Which one of the following is **not** a property of a colloid?

A The solid particles can pass through filter paper.
B An incident beam of light is scattered by the suspended particles.
C Addition of an electrolyte tends to clump the colloid particles together.
D The suspended particles eventually settle out as a sediment.

I2-4
30*
D

When a sample of river water is passed through a filter paper, a certain amount of residue is retained by the filter paper. When a beam of light is passed through the filtrate in a darkened room, appreciable scattering of the light is observed. On the basis of the above observations, the river water would be best described as a

A solution.
B colloid.
C suspension.
D mixture of a suspension and a colloid.
E mixture of a solution and a colloid.

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The next two items refer to the following information:

Mr. King has just installed a Wizzo filter unit for his family swimming pool. He was disappointed at the results obtained, as the water in his pool was not clear.

12-5 If the filter was working efficiently then the cloudiness was probably due to

50

C

A floating material.
B particles in solution.
C colloidal particles.
D chlorine atoms.

12-6 The cloudiness could most easily be removed by

40

B

A filtration.
B flocculation.
C distillation.
D sedimentation.

13 Emulsions

13-1 An emulsion consists of

90

A

A small drops of one liquid dispersed in another liquid.
B particles of liquid dispersed in a gaseous medium.
C small particles of a solid dispersed in a liquid.
D small drops of a liquid dispersed in a solid.

13-2 Which of the following substances is **not** an emulsion?

90

D

A homogenised milk
B mayonnaise
C cosmetic cold cream
D dilute soap solution

13-3 Many substances will form either a temporary or a stable emulsion when shaken with water.

20 Which of the following liquids is **least** likely to do this?

C

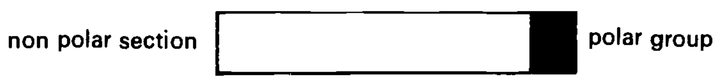
A n-octyl alcohol ($CH_3(CH_2)_7OH$)
B n-decane ($C_{10}H_{22}$)
C ethanol (C_2H_5OH)
D benzene (C_6H_6)

14 Monolayers

14-1 Large molecules like cholesterol may be represented by the following symbol.

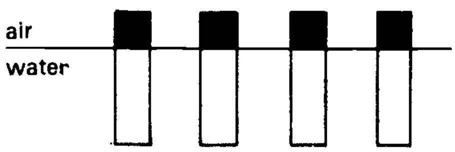
90

C

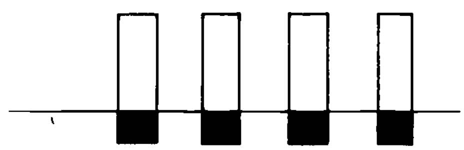


Which of the diagrams below best represents the way these molecules would arrange themselves at the surface of water?

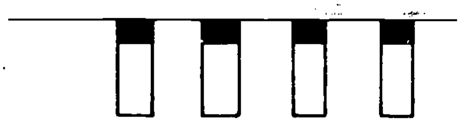
A



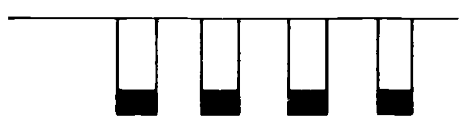
C



B



D



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14-2 40 A | Which of the following compounds is most likely to form a monolayer when added to water?

A $CH_3(CH_2)_{15}OH$

B CH_3  $SO_3^-Na^+$

C $CH_3(CH_2)_3COO^-Na^+$

D CH_3COOH

14-3 80 B | A monolayer of hexadecanol is sometimes placed on the surface of a dam in order to reduce the rate of evaporation. Evaporation is reduced because the

A surface tension of the water in the dam is increased.

B water molecules must pass through small spaces between the hexadecanol molecules in order to escape.

C polar end of the monolayer forms hydrogen bonds with neighbouring water molecules.

D monolayer reflects heat more efficiently than a water–air interface.

15 Surface energy, Surface tension

15-1 80 D | When a glass bottle is broken

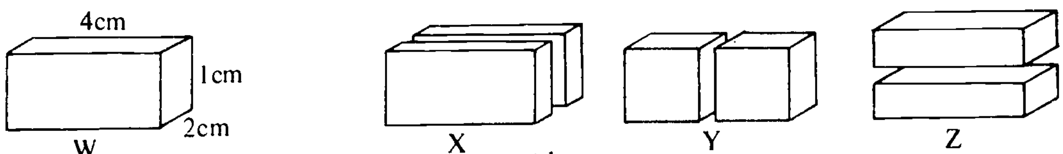
A the total surface energy remains constant.

B the total surface area remains constant.

C the surface tension is decreased.

D energy is stored in the surface of the broken pieces.

15-2 50 D | A block of wood, W, can be cut in half in three different ways as shown by X, Y and Z.



The system with the greatest surface energy would be

A W. B X. C Y. D Z.

15-3 30 B | A cube of iron is equally divided into eight smaller cubes. The fraction

$$\frac{\text{total surface energy of the original cube}}{\text{total surface energy of the eight cubes}}$$

will be approximately

A 1. B $\frac{1}{2}$. C $\frac{1}{4}$. D $\frac{1}{8}$. E $\frac{1}{64}$.

15-4 60 D | A material has a surface energy of $0 \cdot 10\ J\ m^{-2}$. The total surface energy of a block of the material $4 \cdot 0$ m long, $3 \cdot 0$ m wide and $2 \cdot 0$ m deep is

A $0 \cdot 10\ J\ m^{-2}$.

B $1 \cdot 40\ J\ m^{-2}$.

C $2 \cdot 40\ J\ m^{-2}$.

D $5 \cdot 20\ J\ m^{-2}$.

15-5 50 A | The surface tension of a liquid is the

A force acting per unit length of surface.

B force acting per unit area of surface.

C energy acting per unit length of surface.

D pressure acting per unit area of surface.

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15-6 70 A

A fine needle can float on clean water because the

A water–air surface tension overcomes the needle's weight.
B metal–air surface tension is greater than the weight of the water displaced.
C water–air surface tension is equal to the water–metal surface tension.
D water–metal surface tension is greater than the needle's weight.

15-7 70 A

Surface tension has the units

A $N\,m^{-1}$. B $J\,m$. C $N\,m^{-2}$. D $J\,m^{-1}$.

15-8 90 D

The unit $N\,m^{-1}$ which is used for surface tension is dimensionally equivalent to

A J. B $J\,m$. C $J\,m^{-1}$. D $J\,m^{-2}$.

15-9 50* A

The surface tension of a liquid can be measured by the dipping plate method. This method is an example of a

A static technique.
B capillary technique.
C dynamic technique.
D dropping technique.

15-10 80 D

Which of the following measurements is **not** required in the determination of surface tension by the dipping plate method?

A the mass required to balance the plate
B the perimeter of the plate's base
C the acceleration due to gravity
D the solid–vapour surface tension

The next three items refer to the following information:

The surface tension of a liquid can be measured by the drop weight method. This method is based upon the way surface tension opposes the gravitational force on a hanging drop.

15-11 90 C

The formula used to determine surface tension by the drop weight method is

A $\gamma = \dfrac{mgz}{2(l+a)}$.
B $\gamma_{SL} = \gamma_{SG} + \gamma_{LG}\cos\theta$.
C $\gamma = \dfrac{mg}{2\pi Rf}$.
D $\gamma = \dfrac{h\Delta\rho gr}{2\cos\theta}$.

15-12 80 A

If the drops of water ($\gamma = 72\ mN\,m^{-1}$) falling from a particular capillary tube have mass 0·060 g, the mass of drops of acetone ($\gamma = 24\ mN\,m^{-1}$) which would fall from the capillary tube is

A 0·020 g. B 0·060 g. C 0·120 g. D 0·180 g.

15-13 40 B

The surface tension of drops of a liquid falling from a 4 mm capillary tube, compared to that of drops of the same liquid falling from a 2 mm capillary tube, is

A half as large.
B unchanged.
C twice as large.
D four times as large.

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16 Hydrophilic and hydrophobic substances

16-1 60 **B**

A hydrophobic substance is a substance which is

A 'water-hating' and has a high surface energy.
B 'water-hating' and has a low surface energy.
C 'water-loving' and has a high surface energy.
D 'water-loving' and has a low surface energy.

16-2 80 **C**

In which of the following formulae for the surfactant lauric acid has the hydrophilic part been underlined?

A $\underline{CH_3}(CH_2)_{10}COOH$ **C** $CH_3\,(CH_2)_{10}\,\underline{COOH}$
B $\underline{CH_3(CH_2)_{10}}COOH$ **D** $CH_3\,\underline{(CH_2)_{10}}\,COOH$

16-3 80 **C**

Which one of the following clean substances is naturally hydrophilic?

A paraffin wax **C** diamond
B Teflon **D** plastic

17 The liquid-solid interface (wetting, meniscii)

17-1 50 **A, B**

Which **one or more** of the following could occur after repeated handling of a clean glass plate?

A The total surface energy of the glass decreases.
B The glass surface becomes hydrophobic.
C Water spreads more evenly on the glass surface.
D The contact angle (measured through air) of water drops placed on the glass surface increases.

17-2 50 **A**

If a liquid completely wets a solid, the contact angle measured through the liquid is

A 0°. **B** 45°. **C** 90°. **D** 180°.

17-3 50 **C**

Glasses are often rinsed in water after they have been washed.
If droplets of water adhere to the glass surface, a glass is

A clean because water wets clean glass.
B clean because water does not wet clean glass.
C not clean because water wets clean glass.
D not clean because water does not wet clean glass.

17-4 40 **D**

Mercury spilled on a glass surface rapidly forms into drops. As the mercury 'balls up' into a drop the

A surface tension of glass against air is increasing.
B surface tension of mercury against air is decreasing.
C total surface energy of the glass against mercury is increasing.
D total surface energy of the mercury against air is decreasing.

17-5 90 **D**

In which of the following cases is a glue **least** likely to join two materials?

A The surface energies of both materials are high.
B One of the surfaces is hydrophilic.
C The glue is hydrophilic.
D The glue does not wet both materials.

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17-6 | Water shows a concave meniscus in a clean platinum tube, whereas water has a convex meniscus in a Teflon tube.
40
B | The surface energies of platinum, water and Teflon increase in the order

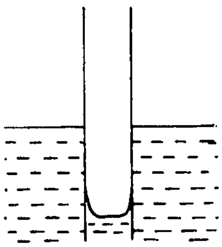
A platinum, water, Teflon.
B Teflon, water, platinum.
C water, platinum, Teflon.
D Teflon, platinum, water.

17-7 | Benzene has a concave meniscus in a clean glass tube, whereas mercury has a convex meniscus. Which
50 | of the following statements is true?
B

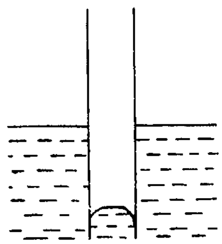
A Benzene has a larger surface tension than mercury and it will wet mercury.
B Benzene has a smaller surface tension than mercury and it will wet mercury.
C Benzene has a larger surface tension than mercury and it will not wet mercury.
D Benzene has a smaller surface tension than mercury and it will not wet mercury.

17-8 | If a liquid does not wet glass, the appearance of the liquid in a glass capillary tube is best represented by
70
C

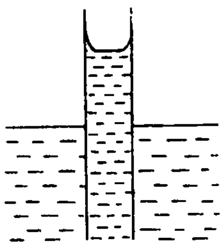
A



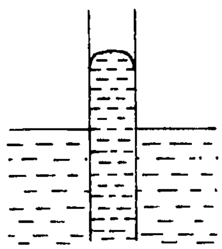
C



B



D



17-9 | If a liquid has a concave meniscus in a capillary tube, the adhesive force between the liquid and glass
60 | would be
B

A greater than the surface tension of the liquid.
B greater than the cohesive force within the liquid.
C less than the cohesive force within the liquid.
D less than the surface tension of the liquid.

18 Surfactants (detergency, froth flotation)

18-1 | The term **adsorption** is used in the study of surface chemistry to refer to the
80
C

A dissolution of hydrophobic liquids in surfactants.
B wetting of a solid by a surface active agent.
C process of concentration of molecules at interfaces.
D rise or fall of liquids in capillary tubes.

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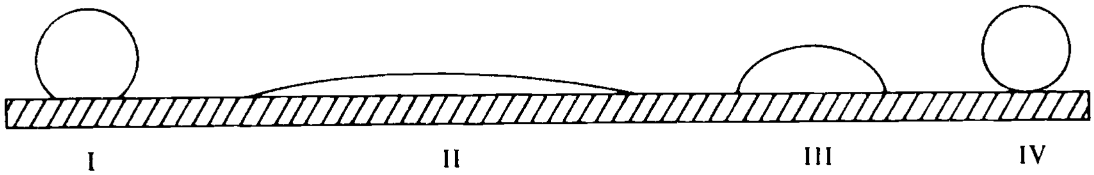
The next three items refer to the following information:

The following diagrams represent side on views of drops on a waxy surface.



18-2 90 **B** If the drop in III is pure water, the appearance of a drop of detergent solution is best represented by

A I. **B** II. **C** III. **D** IV.

18-3 90 **B** The drop with the largest contact angle measured through air is

A I. **B** II. **C** III. **D** IV.

18-4 70 **A** The surface tension of the drops increase in the order

A II, III, I, IV.
B II, I, III, IV.
C IV, III, I, II.
D IV, I, III, II.

18-5 70 **C** Ethanol acts as a surfactant in water. The proportion of ethanol in an alcoholic drink can be estimated from the contact angle of a drop of the drink (measured through the air) on your hand. As the proportion of alcohol in a drop increases, the surface tension

A increases and the contact angle increases.
B increases and the contact angle decreases.
C decreases and the contact angle increases.
D decreases and the contact angle decreases.

18-6 80 **C** Which of the following statements about a concentrated solution of detergent in water is correct?

A It has a higher surface energy than that of clean glass.
B There is an even distribution of detergent molecules throughout the liquid.
C It has a lower surface tension than that of water.
D It has more hydrophilic character than pure water.

18-7 90 **D** The operation of a detergent in washing oily plates involves

A redeposition of oil drops due to repulsion between polar head groups of surfactant molecules.
B adsorption of polar head groups of surfactant molecules in oil droplets.
C froth flotation of hydrophilic oil droplets.
D conversion of a hydrophobic surface to a hydrophilic one.

18-8 70 **D** Redeposition of oil particles when dinner plates are washed is mainly prevented by repulsion between the

A hydrophobic oil molecules and the hydrophobic plate surface.
B hydrophobic part of detergent molecules attached to the oil and the hydrophilic plate surface.
C hydrophilic part of detergent molecules attached to the oil and the hydrophilic plate surface.
D polar groups in detergent molecules attached to the oil and polar groups in detergent molecules near the plate surface.

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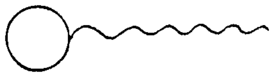
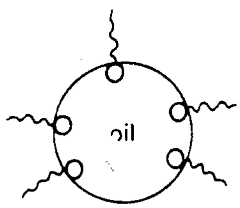
The next two items refer to the following information:

A surfactant molecule may be represented by the symbol below.

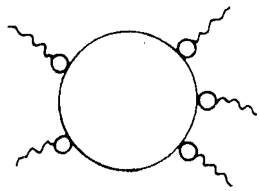


18-9 Which of the following diagrams best represents the orientation of surfactant molecules about a droplet of oil in water?
90
B

A



C



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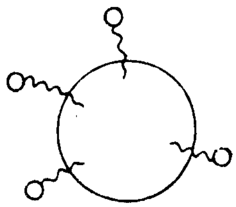

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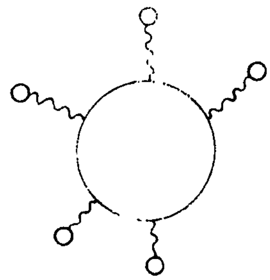
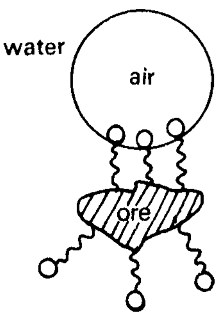


18-10 Which of the diagrams below best represents the action of surfactant molecules during froth flotation?
80
D

A



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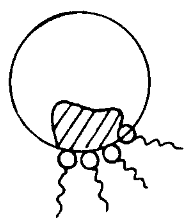

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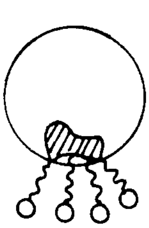

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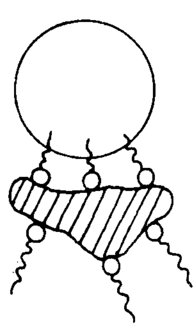

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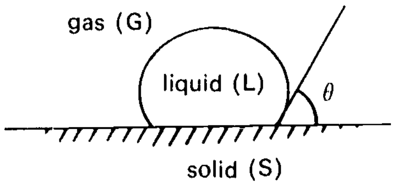
18-11 | Froth flotation is used during the extraction of copper to sort the mineral from impurities. In the process of froth flotation
70
A

A hydrophilic mineral particles become hydrophobic by adsorption of a surfactant.
B hydrophobic mineral particles become hydrophilic in the presence of the frother.
C hydrophobic mineral particles become hydrophilic by adsorption of a surfactant.
D hydrophilic mineral particles become hydrophobic in the presence of the frother.

19 Young's equation

The next three items refer to the following information:

A drop of water rests on a solid as shown.



19-1 | Which of the following equations is correct?
60
C

A $\gamma_{SG} = \gamma_{LG} + \gamma_{SL} \cos \theta$
B $\gamma_{SL} = \gamma_{SG} - \gamma_{LG} \cos \theta$
C $\gamma_{SG} = \gamma_{SL} - \gamma_{LG} \cos \theta$
D $\gamma_{SL} = \gamma_{LG} + \gamma_{SG} \cos \theta$

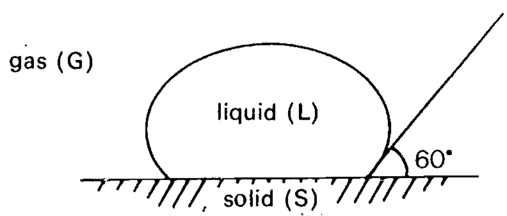
19-2 | The shape of the drop of water suggests that the solid could be clean
70
A

A Teflon.
B glass.
C aluminium.
D diamond.

19-3 | If the drop of water were replaced by a drop of detergent solution
60
D

A θ and γ_{LG} would be smaller.
B θ and γ_{LG} would be larger.
C θ would be smaller and γ_{LG} would be larger.
D θ would be larger and γ_{LG} would be smaller.

19-4 | The diagram below represents a drop of liquid on a surface.
70
C



If the surface tension γ_{LG} were 40 mN m^{-1} and the surface tension γ_{SG} were 100 mN m^{-1}, the surface tension γ_{SL} would be

A 60 mN m^{-1}.
B 80 mN m^{-1}.
C 120 mN m^{-1}.
D 140 mN m^{-1}.

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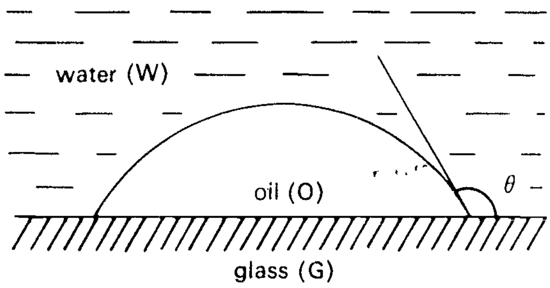
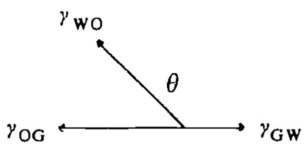
19-5 A drop of oil rests on the bottom of a beaker of water.
70*
A

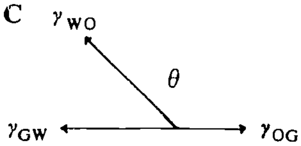


Which of the following diagrams best represents the forces acting at a point where oil, glass and water are in contact?

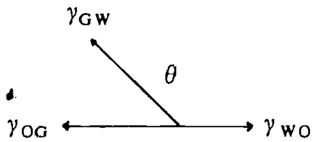
A



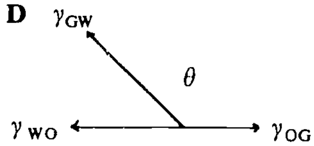
C



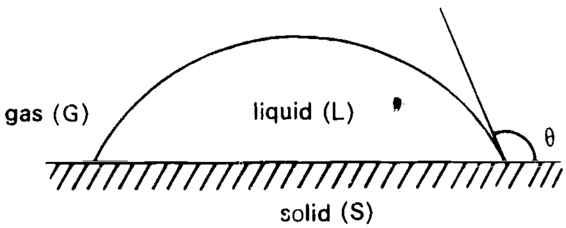
B



D



19-6 A drop of liquid rests on a surface as shown.
80
B



If the surface tensions γ_{SG}, γ_{SL} and γ_{LG} were 100, 60 and 50 mN m^{-1} respectively, then the value of $\cos\theta$ would be

A $-\frac{1}{10}$. **B** $-\frac{4}{5}$. **C** $-\frac{5}{6}$. **D** $-\frac{16}{5}$.

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J STOICHIOMETRY

J1 Law of Conservation of Mass

J1-1 60 **C**

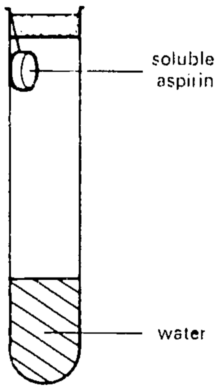
A sample of limestone ($CaCO_3$) was sealed inside a strong glass tube. The mass of the tube and limestone was found to be 156.4 g. The tube was then heated over a Bunsen burner, causing the formation of some quicklime (CaO) and carbon dioxide gas.

The mass of the tube and its contents after the reaction would be (given A_r: Ca = 40, O = 16, C = 12)

A greater than 156.4 g.
B less than 156.4 g.
C equal to 156.4 g.
D either **A**, **B** or **C** depending on the mass of limestone.

J1-2 70 **B**

A tablet of soluble aspirin was suspended above some water in a closed test-tube, as in the diagram.



The mass of the system was found to be 43.01 ±0.06 g. The tube was then inverted and the aspirin and water reacted. After the reaction, the mass of the system was found to be 42.95 ±0.06 g.

The most likely explanation of this result is that

A the mass of the total system decreased as a result of the reaction.
B the mass of the system remained constant within the limit of experimental error.
C the chemical reaction produced a slight, but definite, decrease in mass of the enclosed mixture.
D one of the products of the reaction was a gas.

J1-3 40 **D**

For which of the following chemical reactions is the total mass of the products less than the total mass of the reactants?

A $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
B $Na(s) + 2H_2O(l) \rightarrow Na^+(aq) + 2OH^-(aq) + \frac{1}{2}H_2(g)$
C $Na(g) \rightarrow Na^+(g) + e^-$
D none of the above

J1-4 60 **C**

Which one of the following does **not** change during any chemical reaction?

A total number of molecules in the system
B total volume of the system
C total mass of the system
D temperature of the system

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J1-5
40
B

Consider the following equations:

I $Cl_2 + \frac{1}{2}O_2 \rightarrow Cl_2O$
II $H_2S_2O_7 \rightarrow H_2SO_4 + SO_3$
III $C_3H_8 + O_2 \rightarrow 3CO_2 + 2H_2O$

One of these equations does **not** obey

A the Law of Constant Composition.
B the Law of Conservation of Mass.
C Avogadro's Law.
D the Law of Definite Proportions.

J1-6
40
A

Hydrogen gas and iodine solid react to form hydrogen iodide gas according to the equation:

$$H_2(g) + I_2(s) \rightarrow 2HI(g)$$

25.4 g of I_2 and 4.0 g of H_2 are reacted together and 27.4 g of HI forms. Assuming that the reactant that is **not** in excess reacts completely, the mass of the **excess** reactant left at the end of the reaction is

A $25.4 + 4.0 - 27.4$ g.
B $27.4 + 4.0 - 25.4$ g.
C $\frac{1}{2} \times (25.4 + 4.0) - 27.4$ g.
D impossible to determine from the information given.

J2 Chemical equations

J2-1
90
D

In the reaction represented by the equation

(3) $CuSO_4$ + (2) Al → (1) $Al_2(SO_4)_3$ + (3) Cu

the coefficients (which have been circled) represent

A the amounts of each substance involved in the reaction, measured in mole.
B the numbers of actual molecules of each substance involved in the reaction.
C the ratios of masses of substances involved in the reaction.
D the mole ratio of substances involved in the reaction.

J2-2
90
B

The following equation represents the decomposition of lead(II) nitrate on heating:

$$xPb(NO_3)_2 \rightarrow yPbO + zNO_2 + O_2$$

The respective values of x, y and z are

A 1, 2, 2. **B** 2, 2, 4. **C** 2, 3, 4. **D** 4, 4, 8.

J2-3
90
D

Consider the following equation:

$$wZnS + xO_2 \rightarrow yZnO + zSO_2$$

Of the following, the coefficients w, x, y and z which balance the equation are, respectively,

A 2, 2, 3, 2. **B** 1, 3, 1, 1. **C** 2, 3, 2, 1. **D** 2, 3, 2, 2.

J3 Mole-mole relationships

J3-1
40
D

The reaction of sodium sulfite with hydrogen chloride may be represented by the following equation:

$$Na_2SO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + SO_2(g)$$

On the basis of the information in the equation, which one of the following is true?

A When one mole of Na_2SO_3 is treated with acid, one mole of SO_2 will always be produced.
B Na_2SO_3 and HCl must always be present in the mole ratio of 1:2 for a reaction to take place.
C The ratio by mass of Na_2SO_3 to HCl in a reaction mixture of stoichiometric proportions is 1:2.
D 0.4 mol of water will be produced when 0.8 mol of HCl reacts completely with excess Na_2SO_3.

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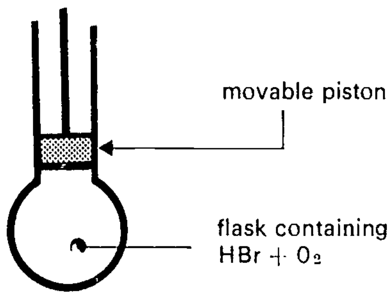
J3-2 50* C

Gaseous hydrogen bromide oxidizes readily at 500 °C. This reaction may be represented by the following equation:

$$4HBr(g) + O_2(g) \rightarrow 2H_2O(g) + 2Br_2(g)$$

0.40 mol of HBr and 0.20 mol of O_2 at 120 °C were placed in a flask fitted with a movable piston, as shown in the diagram, and heated until a reaction took place. When the reaction was complete, the contents of the flask were cooled to 120 °C, and the position of the piston was observed.



Which one of the following describes the likely effect of this procedure on the piston?

A The piston would not have moved.

B The piston would have moved up and then moved back to its original position.

C The piston would have moved up and then back past its original position into the flask.

D The piston would have moved up the neck of the flask and stayed above its original position.

The next two items refer to the following information:

A solution containing 0.010 mol of OH^- was added to a solution containing 0.005 mol of Ca^{2+} and a reaction occurred which may be represented by the equation

$$Ca^{2+}(aq) + 2OH^-(aq) \rightarrow Ca(OH)_2(s)$$

The resulting precipitate was removed by filtration and found to consist of only 0.003 mol of $Ca(OH)_2$.

J3-3 60 B

The amount of OH^- remaining in solution was

A 0.001 mol. **B** 0.004 mol. **C** 0.007 mol. **D** 0.010 mol.

J3-4 80 D

The fact that OH^- ions remained in solution suggests that

A Ca^{2+} ions and OH^- ions do not react in the mole ratio of 1:2.

B Ca^{2+} ions are more difficult to precipitate than OH^- ions.

C some of the $Ca(OH)_2$ expected to be in the precipitate had evaporated before filtration.

D $Ca(OH)_2$ is slightly soluble and the reaction does not go to completion.

J3-5 60* B

When a sample of a hydrocarbon is burned in excess oxygen, the reaction produces equal numbers of CO_2 and H_2O molecules. It follows that

A the molecular formula of the compound must be C_2H_4.

B the empirical formula of the compound must be CH_2.

C the molecular formula of the compound must be CH_2.

D the empirical formula of the compound must be C_2H_4.

E none of the above statements is correct.

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J4 Mole-mass relationships

J4-1
70
B

An excess of dilute nitric acid is added to 0.3 mol of calcium carbonate ($CaCO_3$). (A_r: Ca = 40, C = 12, O= 16)

The mass of carbon dioxide produced by this reaction is

A 0.3 × 22.4 g.
B 0.3 × 44 g.
C 0.3 × 60 g.
D 0.3 × 100 g.
E 0.3 × 100 × 44 g.

J4-2
50
D

In the first stage of one method of manufacturing sulfuric acid, sulfur is burnt in excess oxygen to form sulfur dioxide. The mass of sulfur dioxide formed from 10.0 mol of S_8 molecules is (given M_r: S_8 = 256, SO_2 = 64)

A $\frac{8 \times 64}{256}$ g.
B 8 × 32 g.
C 10 × 64 g.
D 80 × 64 g.

J4-3
50
A

What mass of lead(II) iodide, PbI_2, is precipitated when a solution containing 1.00 mol of lead(II) nitrate, $Pb(NO_3)_2$, is mixed with a solution containing 0.50 mol of potassium iodide, KI?

(Assume complete precipitation occurs.)

(M_r PbI_2 = 461)

A 461 × 0.25 g
B 461 × 0.50 g
C 461 × 1.00 g
D 461 × 2.00 g

J4-4
50
B

A solution containing 0.0100 mol of Ag^+ is added to a solution containing 0.0100 mol of Cl^-. The precipitated AgCl is collected, weighed, and found to have a mass of 1.38 g. The expected mass of AgCl, if precipitation is complete, is 1.44 g. The amount of AgCl (as Ag^+ and Cl^-) remaining in solution is

A $\frac{1.38}{144}$ mol.
B $\frac{0.06}{144}$ mol.
C $\frac{0.0100 \times 1.38}{1.44}$ mol.
D $\frac{0.06}{0.0100}$ mol.

J4-5
30
B

The following equation represents the combustion of methane, CH_4 (M_r = 16) in air.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

The amount of CO_2 (M_r = 44) formed when 5.4 g of methane is completely burned in air is given by

A $\frac{5.4 \times 16}{44}$ mol.
B $\frac{5.4}{16}$ mol.
C $\frac{5.4}{44}$ mol.
D $\frac{5.4 \times 44}{16}$ mol.

J4-6
50
C

0.715 g of silver chloride, AgCl, was precipitated when an excess of silver nitrate ($AgNO_3$) was added to a solution containing 1.67×10^{-3} mol of MCl_x.

The value of x is (given M_r AgCl = 143)

A 1.
B 2.
C 3.
D 4.
E 5.

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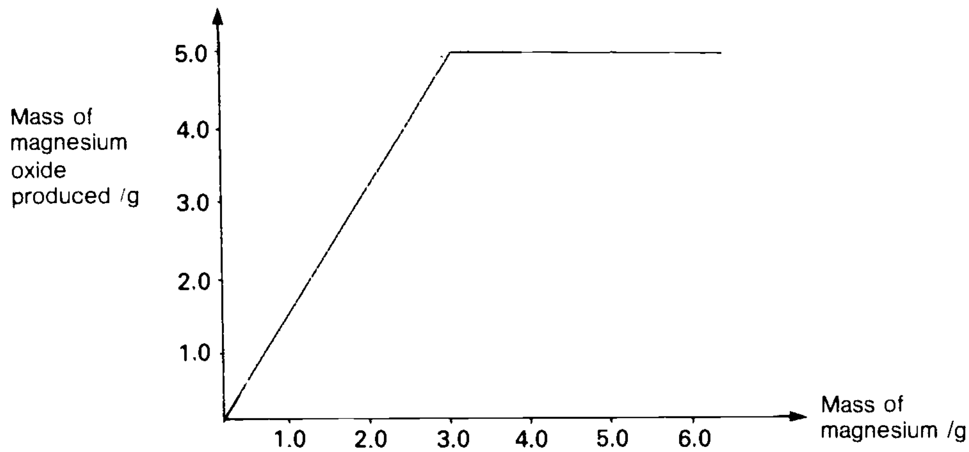
J5 Mass-mass relationships

The next three items refer to the following information

When burnt in oxygen, magnesium metal reacts rapidly to completion. The graph shows the results of adding different masses of magnesium to a constant mass of oxygen gas, and the corresponding mass of magnesium oxide produced.



J5-1 60 **B**
To form 5.0 g of magnesium oxide, the mass (in g) of oxygen required is

A 1.6. **B** 2.0. **C** 3.3. **D** 5.0.

J5-2 60 **A**
The empirical formula of magnesium oxide is MgO. The value of the following ratio of masses:

$$\frac{\text{mass of one atom of magnesium}}{\text{mass of one atom of oxygen}}$$

must be

A 3:2. **B** 2:3. **C** 2:5. **D** 5:2.

J5-3 50 **D**
The flat part of the graph represents the situation when

A there is an excess of oxygen in the reacting mixture.
B the ratio of the mass of magnesium to the mass of oxygen in the reacting mixture is a constant.
C no reaction is occurring between the magnesium and oxygen.
D there is an excess of magnesium in the reacting mixture.

J5-4 70 **A**
The reaction between magnesium and sulfur dioxide may be represented by the following equation:

$$2Mg(s) + SO_2(g) \rightarrow 2MgO(s) + S(s)$$

What is the mass of sulfur that is obtained when 0.20 g of SO_2 reacts with excess magnesium?

(A_r:S = 32, O = 16, Mg = 24)

A 0.10 g **B** 0.20 g **C** 6.4 g **D** 32 g

J5-5 30 **D**
The metal lithium burns in air to form lithium oxide (Li_2O). The mass of lithium which would be needed to form 15.0 g of the oxide is closest to (given A_r: Li = 7, O = 16)

A 0.70 g. **B** 2.74 g. **C** 3.22 g. **D** 6.95 g.

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J5-6
60
D

In the thermite process for on-the-spot welding of steel, iron oxide is reduced by aluminium to produce aluminium oxide and iron with the evolution of much heat. The reaction is represented by the equation

$$8Al + 3Fe_3O_4 \rightarrow 4Al_2O_3 + 9Fe$$

If the process is 85% efficient, the mass of iron which can be produced from 5 g of aluminium is (given A_r: Al = 27, Fe = 56)

A $\frac{100}{85} \times \frac{5}{27} \times \frac{8}{9} \times 56$ g.

B $\frac{85}{100} \times \frac{5}{27} \times \frac{8}{9} \times 56$ g.

C $\frac{100}{85} \times \frac{5}{27} \times \frac{9}{8} \times 56$ g.

D $\frac{85}{100} \times \frac{5}{27} \times \frac{9}{8} \times 56$ g.

J5-7
40
D

Each of the compounds below can be treated to produce CO_2 gas. Which one is likely to provide the greatest mass of CO_2 per gram of original compound? (A_r: Ca = 40, K = 39, Na = 23, Mg = 24)

A $CaCO_3$

B Na_2CO_3

C K_2CO_3

D $MgCO_3$

E none of **A**, **B**, **C**, or **D** as equal amounts of CO_2 would be produced

J5-8
40
C

Consider the following reactions:

$$2Al + 6H^+ \rightarrow 2Al^{3+} + 3H_2$$
$$Zn + 2H^+ \rightarrow Zn^{2+} + H_2$$
$$2Li + 2H_2O \rightarrow 2Li^+ + 2OH^- + H_2$$
$$Ca + 2H_2O \rightarrow Ca^{2+} + 2OH^- + H_2$$

If 10.0 g of each of Al, Zn, Li and Ca react as in the above equations, which would give the largest volume of gas? (Assume that all gas volumes are measured under the same conditions.)

(A_r: Al = 27.0, Zn = 65.4, Li = 7.0, Ca = 40.0)

A Al **B** Zn **C** Li **D** Ca

J5-9
70
A

28.5 cm^3 of benzene (density 0.88 g cm^{-3}) is reacted with an excess of bromine to produce the compound C_6H_5Br according to the equation

$$C_6H_6 + Br_2 \rightarrow C_6H_5Br + HBr$$

The mass of C_6H_5Br formed, if the reaction goes to completion, is (given M_r: C_6H_6 = 78, C_6H_5Br = 157)

A $\frac{28.5 \times 0.88 \times 157}{78}$ g.

B $\frac{28.5 \times 157}{78 \times 0.88}$ g.

C $\frac{28.5 \times 0.88 \times 157}{79}$ g.

D $\frac{28.5 \times 0.88}{78 \times 157}$ g.

J5-10
40
B

6.30 g of element X combines with chlorine to form 9.47 g of a compound of empirical formula XCl_3. The relative atomic mass of element X is given by (given A_r Cl = 35.5)

A $\frac{3 \times 6.30 \times 35.5}{9.47}$.

B $\frac{3 \times 6.30 \times 35.5}{(9.47 - 6.30)}$.

C $\frac{6.30 \times 35.5}{3(9.47 - 6.30)}$.

D $\frac{6.30 \times 35.5}{3 \times 9.47}$.

J5-11
50
B

2.00 g of the sulfite of an element Z was oxidized to the sulfate, and the sulfate ion precipitated as 6.00 g of pure dry barium sulfate (M_r = 233). The percentage of sulfur in the sulfite of Z would be (given A_r: S = 32, O = 16)

A 50.

B $\frac{6.00 \times 32 \times 100}{233 \times 2.00}$.

C $\frac{4.00 \times 100}{6.00}$.

D $\frac{6.00 \times 96 \times 100}{233 \times 2.00}$.

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J5-12 60 C

0.26 g of metal X is added to a solution containing silver ions. 1.08 g of silver is precipitated and all of metal X is dissolved. The reaction may be written as

$$aX(s) + bAg^{+}(aq) \rightarrow bAg(s) + X^{a+}(aq)$$

From the data given, the ratio a:b is (given A_r: X = 52, Ag = 108)

A 2:1. **B** 1:1. **C** 1:2. **D** 2:3. **E** 3:2.

J5-13 30 C

Calcium carbonate is decomposed by strong heating to calcium oxide and carbon dioxide. A 6.0 g sample of impure limestone consisting of calcium carbonate and silica was heated strongly until no further decrease in mass occurred, the final mass being 4.9 g.

The mass of silica present in the limestone sample is (given M_r: CO_2 = 44, $CaCO_3$ = 100)

A 1.1 g. **B** 2.5 g. **C** 3.5 g. **D** 3.8 g.

J5-14 40 B

Chromium metal is extracted from the mineral chromite, $Fe(CrO_2)_2$, by the following steps

(i) $4Fe(CrO_2)_2 + 8Na_2CO_3 + 7O_2 \rightarrow 8Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$
(ii) $2Na_2CrO_4 + H_2SO_4 \rightarrow Na_2Cr_2O_7 + H_2O + Na_2SO_4$
(iii) $Na_2Cr_2O_7 + 2CO \rightarrow Cr_2O_3 + Na_2CO_3 + CO$
(iv) $Cr_2O_3 + 2Al \rightarrow Al_2O_3 + 2Cr$

The maximum mass of chromium which could be obtained from 200 kg of pure chromite is (given A_r Cr = 52.0; M_r $Fe(CrO_2)_2$ = 224)

A $\frac{200}{224} \times 52.0 \times \frac{1}{4}$ kg.

B $\frac{200}{224} \times 52.0 \times 2$ kg.

C $\frac{200}{224} \times 52.0 \times 8$ kg.

D $\frac{200}{224} \times 52.0 \times \frac{1}{2}$ kg.

J5-15 40 A

Arsenic ingested by humans exists in the stomach as orthoarsenic acid H_3AsO_4. As small a quantity as 0.0005 g of arsenic may be identified by mixing the contents of the stomach with HCl and then adding zinc. The arsine gas, AsH_3, which is liberated is passed through a heated glass tube in which it decomposes. The reactions involved are

$$Zn + 2H^{+} \rightarrow Zn^{2+} + H_2$$
$$4H_2 + H_3AsO_4 \rightarrow AsH_3 + 4H_2O$$
$$2AsH_3 \rightarrow 2As + 3H_2$$

What is the minimum mass of Zn (A_r = 65) which will yield 0.0005 g of As (A_r = 75)?

A $4 \times \frac{0.0005}{75} \times 65$ g

B $\frac{1}{4} \times \frac{0.0005}{75} \times 65$ g

C $4 \times \frac{0.0005}{75} \times 65 \times 2$ g

D $\frac{1}{4} \times \frac{0.0005}{75} \times 65 \times \frac{1}{2}$ g

J5a Percentage yield

J5a-1 80 B

A chemical reaction produces m_1 gram of product. If m_2 gram were the theoretical mass of product which could be formed if the reaction proceeded to completion, the percentage yield of the reaction would be

A $\frac{m_2 - m_1}{m_2} \times 100\%$.

B $\frac{m_1}{m_2} \times 100\%$.

C $\frac{m_2}{m_1} \times 100\%$.

D $\frac{m_2}{m_2 - m_1} \times 100\%$.

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J5a-2 70 D | 1·00 g of ethanoic acid (M_r = 60·1) was synthesized from 1·00 g of ethanol (M_r = 46·1). The percentage yield was

A 100%.

B $\frac{14 \cdot 0 \times 100}{46 \cdot 1}$ %.

C $\frac{14 \cdot 0 \times 100}{60 \cdot 1}$ %.

D $\frac{46 \cdot 1 \times 100}{60 \cdot 1}$ %.

E $\frac{60 \cdot 1 \times 100}{46 \cdot 1}$ %.

J5a-3 60 B | Tetrammine copper(II) sulfate may be prepared by the reaction

$$CuSO_4(aq) + 4NH_3(aq) \rightarrow Cu(NH_3)_4SO_4(aq).$$

In a particular experiment, 3·80 g of anhydrous copper(II) sulfate (M_r = 159·5) was treated with excess NH_3 solution. Ethanol was added to the mixture and 2·32 g of solid $Cu(NH_3)_4SO_4.H_2O$ (M_r = 245·5) was obtained. The percentage yield would be

A $\frac{2 \cdot 32 \times 100}{3 \cdot 80}$ %.

B $\frac{2 \cdot 32 \times 159 \cdot 5 \times 100}{245 \cdot 5 \times 3 \cdot 80}$ %.

C $\frac{3 \cdot 80 \times 100}{2 \cdot 32}$ %.

D $\frac{3 \cdot 80 \times 245 \cdot 5 \times 100}{159 \cdot 5 \times 2 \cdot 32}$ %.

J6 Reactions in solution

J6-1 80 B | When 20 cm^3 of 1 M $BaCl_2$ solution is added to 40 cm^3 of 2 M K_2SO_4 solution, the mass of the $BaSO_4$ precipitate formed is (given A_r: K = 39, S = 32, O = 16, Ba = 137, Cl = 35.5)

A 2.33 g. B 4.66 g. C 9.32 g. D 18.64 g.

J6-2 50 B | Assuming precipitation is complete, the mass of $Fe(OH)_3$ (M_r = 107) obtained when 9.0 cm^3 of 0.10 M NaOH solution is added to 500 cm^3 of 1.00 M $FeCl_3$ solution is

A $\frac{9 \times 0.1 \times 107}{1000}$ g.

B $\frac{9 \times 0.1 \times 107}{1000 \times 3}$ g.

C $\frac{3 \times 9 \times 0.1 \times 107}{100}$ g.

D $\frac{3 \times 0.1 \times 107}{1000 \times 9}$ g.

The next two items refer to the following information

Calcium chloride solution reacts with sodium hydroxide solution according to the following equation:

$$CaCl_2(aq) + 2NaOH(aq) \rightarrow Ca(OH)_2(s) + 2NaCl(aq)$$

10 cm^3 of 1.0 M $CaCl_2$ solution is added to 10 cm^3 of 1.0 M NaOH solution, and the white precipitate formed is collected and weighed.

J6-3 50 A | The mass of white precipitate expected from the above procedure is (given M_r: $CaCl_2$ = 111.0, NaOH = 40.0, $Ca(OH)_2$ = 74.0, NaCl = 58.5)

A 0.37 g. B 0.74 g. C 1.17 g. D 1.48 g.

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J6-4 60 D

The actual mass of precipitate collected is found to be 0.34 g. This value is less than expected because

A there was insufficient calcium chloride present in the initial solution to react with all of the sodium hydroxide.

B there was insufficient sodium hydroxide present in the initial solution to react with all of the calcium chloride.

C all of the calcium ions have combined with all of the hydroxide ions, but only some of the calcium hydroxide has precipitated.

D the reaction has not gone to completion, and some of the calcium ions and hydroxide ions remain in solution.

J6-5 30 C

30 cm^3 of a 2 M solution of $C_2O_4^{2-}$ is added to 20 cm^3 of a 2 M solution of Ce^{4+}. The equation for the reaction is

$$2Ce^{4+} + C_2O_4^{2-} \rightleftharpoons 2Ce^{3+} + 2CO_2$$

The amount of excess reagent remaining will be

A 0.010 mol. B 0.020 mol. C 0.040 mol. D 0.060 mol.

The next two items refer to the following information

When solutions of $AgNO_3$ and K_2CrO_4 are mixed, Ag_2CrO_4 precipitates according to the equation

$$2Ag^+(aq) + CrO_4^{2-}(aq) \rightarrow Ag_2CrO_4(s)$$

10 cm^3 of 0.1 M $AgNO_3$ is added to 20 cm^3 of 0.05 M K_2CrO_4.

J6-6 30* A

The concentration of K^+ in the resulting solution after reaction is

A $2 \times 0.05 \times (20/30)$ M.

B $0.05 \times (20/30)$ M.

C 2×0.05 M.

D $0.0005 \times (1000/30)$ M.

E 0.0005 M.

J6-7 30 D

The species present in excess, and the amount of that species left unreacted is

A 0.05 mol $AgNO_3$.

B 0.05 mol K_2CrO_4.

C 0.0005 mol $AgNO_3$.

D 0.0005 mol K_2CrO_4.

E neither species is in excess as both reagents are entirely used up.

J6-8 30 D

The volume of 0·1 M H_2SO_4 solution required to prepare 5·62 g of hydrated iron (III) sulfate (M_r = 562) from iron (III) oxide is

A 10 cm^3. B 30 cm^3. C 100 cm^3. D 300 cm^3. E 1 dm^3.

J6-9 20 D

0.16 g of limestone reacts completely with 100 cm^3 of 0.02 M HCl. The percentage by mass of $CaCO_3$ in the limestone is (given M_r $CaCO_3$ = 100)

A $\frac{0.16 \times 1000 \times 100}{100 \times 0.02}$.

B $\frac{100 \times 0.02 \times 2 \times 0.16 \times 100}{1000 \times 100}$.

C $\frac{100 \times 0.02 \times 100 \times 100}{1000 \times 0.16}$.

D $\frac{100 \times 0.02 \times 100 \times 100}{1000 \times 2 \times 0.16}$.

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J6-10 20* **D**

The concentration of an acid may be determined by reacting it with a crystal of calcium carbonate and determining the loss in mass of the crystal.

If 20 cm^3 of a solution of dilute hydrochloric acid produced a loss in mass of 0.123 g in the calcium carbonate crystal (M_r = 100.1), the concentration of the acid was

A $\frac{0.123}{100.1} \times \frac{1000}{20}$ M.

B $\frac{0.123}{100.1} \times \frac{2}{1} \times \frac{20}{1000}$ M.

C $\frac{0.123}{100.1} \times \frac{1}{2} \times \frac{1000}{20}$ M.

D $\frac{0.123}{100.1} \times \frac{2}{1} \times \frac{1000}{20}$ M.

E $\frac{0.123}{100.1} \times \frac{1}{2} \times \frac{20}{1000}$ M.

J6-11 30 **A**

During one stage in a process for the extraction of uranium from pitchblende, ammonia is added to 600 dm^3 of an acid solution containing UO_2^{2+} ions. These ions are completely converted to an insoluble compound, $(NH_4)_2U_2O_7$, called 'yellowcake'.

If 37 kg of $(NH_4)_2U_2O_7$ is precipitated, the concentration of UO_2^{2+} in the acid solution was

(M_r: UO_2^{2+} = 270, $(NH_4)_2U_2O_7$ = 624)

A $\frac{37 \times 10^3 \times 2}{624 \times 600}$ M.

B $\frac{37 \times 10^3}{624 \times 600}$ M.

C $\frac{37 \times 10^3}{624 \times 2 \times 600}$ M.

D $\frac{37 \times 10^3}{270 \times 600}$ M.

J6-12 40 **D**

A metallic element, *X*, reacts with hydrogen ions according to the equation

$$X(s) + 2H^+(aq) \rightarrow X^{2+}(aq) + H_2(g)$$

If 0.195 g of the metal *X* reacts with exactly 20 cm^3 of 0.30 M hydrochloric acid solution, the relative atomic mass of the metal is

A $\frac{0.195 \times 1000}{20 \times 0.30}$.

B $\frac{0.195 \times 1000}{20 \times 0.30 \times 2}$.

C $\frac{20 \times 0.30}{1000 \times 2 \times 0.195}$.

D $\frac{0.195 \times 1000 \times 2}{20 \times 0.30}$.

J6-13 60 **D**

0.080 g of substance *X* (M_r = 64.0) reacts exactly with 31.25 cm^3 of a 0.100 M solution of *Y* to produce substance Z. The values of *a* and *b* in the equation $aX + bY \rightarrow cZ$ are, respectively,

A 1, 2. **B** 2, 3. **C** 3, 2. **D** 2, 5. **E** 5, 2.

J6-14 20 **B**

6·834 g of hydrated iron (II) sulfate $FeSO_4.7H_2O$ was weighed out, transferred to a standard flask, acidified with sulfuric acid and made up to 250 cm^3. A 25 cm^3 aliquot of this solution was transferred by pipette to a conical flask and titrated against some previously standardized potassium permanganate solution. On the basis of the mass of salt taken and the known value of the molarity of the permanganate, a titre of 23·10 cm^3 was expected. In fact the titre was 22·13 cm^3.

Which is the best explanation for this difference between observed and expected values?

A The iron (II) sulfate was partially dehydrated before weighing.

B The iron (II) sulfate was partially oxidized.

C Between the time of standardization and its use in the titration, the potassium permanganate had become partially reduced to manganese dioxide, which precipitated from solution.

D The potassium permanganate had become diluted, possibly due to water in the burette.

E Too much sulfuric acid had been added to the iron (II) sulfate.

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J6-15
40
A

Pure iron dissolves in dilute sulfuric acid as shown in the following equation.

$$Fe(s) + 2H^+(aq) \rightarrow Fe^{2+}(aq) + H_2(g)$$

$Fe^{2+}(aq)$ ions are oxidized to $Fe^{3+}(aq)$ ions by an aqueous solution of potassium permanganate, $KMnO_4$, according to the equation

$$5Fe^{2+}(aq) + MnO_4^-(aq) + 8H^+(aq) \rightarrow 5Fe^{3+}(aq) + Mn^{2+}(aq) + 4H_2O(l).$$

0.1 g of iron is dissolved in dilute sulfuric acid. What volume of 0.02 M potassium permanganate solution is required to oxidize the resulting $Fe^{2+}(aq)$ solution?

(A_r Fe = 56)

A $\frac{0.1}{56} \times \frac{1}{5} \times \frac{1000}{0.02}$ cm^3

B $\frac{0.1}{56} \times \frac{5}{1} \times \frac{1000}{0.02}$ cm^3

C $\frac{0.1}{56} \times \frac{1}{5} \times \frac{0.02}{1000}$ cm^3

D $\frac{56}{0.1} \times \frac{5}{1} \times \frac{0.02}{1000}$ cm^3

J6-16
10
D

The mass of solid anhydrous potassium dichromate (M_r = 294) required to react exactly with 150 cm^3 of 0.10 M iron(II) sulfate solution acidified with sulfuric acid is

A $\frac{150 \times 0.10}{1000} \times \frac{294}{1}$ g.

B $\frac{150 \times 0.10}{1000} \times \frac{294}{2}$ g.

C $\frac{150 \times 0.10}{1000} \times \frac{294}{5}$ g.

D $\frac{150 \times 0.10}{1000} \times \frac{294}{6}$ g.

E $\frac{150 \times 0.10 \times 2}{1000} \times \frac{294}{1}$ g.

J6-17
20*
D

A sample of sand was known to have an iron content of 0·16 %. A student attempted to analyse the sample by extraction of the iron with an acid solution, conversion to Fe^{2+} and titration with standard acidified $KMnO_4$ solution. From the recorded titre, he calculated the iron content to be 0·13 %.

Which of the following could account for the incorrect result?

A The mass of the sample of sand was greater than measured by the chemist.

B The $KMnO_4$ solution used by the chemist had partially decomposed since its standardization.

C Another metal ion present in the sand also reacted with the $KMnO_4$ solution.

D The volume of $KMnO_4$ used in the titration was larger than recorded by the chemist.

J7 Reactions in the gas phase

J7-1
70
A

Ammonia gas can be completely decomposed to its elements, according to the equation:

$$2NH_3 \rightarrow N_2 + 3H_2$$

If all measurements are made at the same temperature and pressure, the volumes of ammonia consumed and nitrogen produced when 12 m^3 of hydrogen gas is formed are

A 8 m^3 and 4 m^3.

B 16 m^3 and 4 m^3.

C 24 m^3 and 36 m^3.

D 12 m^3 and 12 m^3.

J7-2
40
B

20 cm^3 of ethane, C_2H_6, is burned in excess oxygen. The following equation represents this reaction:

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$$

All gas volumes are measured at 120 °C and 1.013×10^5 Pa.

The total volume of gas produced by the reaction is

A $(4 + 6) \times 20$ cm^3.

B $\frac{(4 + 6) \times 20}{2}$ cm^3.

C $\frac{(4 + 6) \times 20 \times 273}{2 \times 393}$ cm^3.

D $\frac{20 \times (4 + 6)}{22400}$ cm^3.

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The next two items refer to the following information

20 cm^3 of NH_3 and 20 cm^3 of O_2 measured at STP react. This reaction may be represented by the following equation:

$$4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(g)$$

After the reaction, gas volumes are again measured at STP.

J7-3 60 **B** What is the volume of oxygen gas that remains unreacted?

A 0 cm^3 **B** 5 cm^3 **C** 15 cm^3 **D** 20 cm^3

J7-4 80 **B** What is the volume of nitrogen gas produced?

A 5 cm^3 **B** 10 cm^3 **C** 15 cm^3 **D** 20 cm^3

J7-5 20 **B** The industrial synthesis of methanol, CH_3OH, involves reaction of carbon monoxide and hydrogen in the presence of a metal oxide catalyst. In a particular synthesis 20 m^3 of CO gas and 30 m^3 of H_2 gas were reacted to form CH_3OH gas at 400 °C and 3×10^7 Pa.

The final volume of gas at this temperature and pressure would be

A 15 m^3. **B** 20 m^3. **C** 30 m^3. **D** 40 m^3. **E** 50 m^3.

J7-6 50 **C** Carbon monoxide is used as a gaseous fuel in several industrial processes. It reacts readily with oxygen according to the equation

$$2CO + O_2 \rightarrow 2CO_2$$

Assuming all volumes are measured at the same temperature and pressure, what is the percentage CO_2 (by volume) in the gas which results from complete reaction of 4.0 dm^3 of carbon monoxide and 4.0 dm^3 of oxygen?

A 100% **B** 50% **C** 67% **D** 33%

J7-7 20 **B** 40 dm^3 of sulfur dioxide was reacted with a large volume of oxygen according to the equation

$$2SO_2 + O_2 \rightarrow 2SO_3$$

If all volumes are measured at the same temperature and pressure, what contraction occurred in the total gas volume?

A 0 dm^3 **B** 20 dm^3 **C** 40 dm^3 **D** 60 dm^3

J7-8 40 **C** 50 dm^3 of methane gas was burnt by a gas heater. Assuming air is $\frac{1}{5}$ by volume of oxygen, and carbon dioxide and water vapour were the only combustion products, what volume of air at the same temperature and pressure was required by the heater?

A 100 dm^3 **B** 250 dm^3 **C** 500 dm^3 **D** 1000 dm^3

J7-9 20 **B** 500 cm^3 of hydrogen gas and 500 cm^3 of oxygen gas, each measured at 273 °C and 1×10^5 Pa pressure, were mixed and sparked in a closed vessel. The contents of the vessel were then cooled to 0 °C at 1×10^5 Pa pressure. The resultant volume would be closest to

A zero.
B 125 cm^3.
C 250 cm^3.
D 500 cm^3.
E 1000 cm^3.

J7-10 30 **D** 50.0 cm^3 of the gaseous hydride of an element decomposes on heating to give the element and 100 cm^3 of hydrogen gas, measured at the same temperature and pressure. How many hydrogen atoms does one molecule of the hydride contain?

A 1 **B** 2 **C** 3 **D** 4

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J7-11 50 B | 10 cm^3 of a gaseous oxide of element X required 20 cm^3 of oxygen gas for complete combustion. 30 cm^3 of a different oxide, XO_2, was the only product formed.

All volumes were measured at the same temperature and pressure. The formula for the original oxide is

A X_2O_3. **B** X_3O_2. **C** X_3O_4. **D** X_4O_{10}.

J7-12 20 E |

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

25 per cent of a mixture of 1 mol of N_2 and 3 mol of H_2 reacts according to the equation above in a sealed vessel at constant temperature.

Which of the following represents the fraction $\frac{\text{final pressure}}{\text{initial pressure}}$?

A 1/8 **B** 1/4 **C** 1/2 **D** 3/4 **E** 7/8

J8 Mass-gas volume relationships

J8-1 80 B | Heptane burns in air according to the equation

$$C_7H_{16}(l) + 11O_2(g) \rightarrow 7CO_2(g) + 8H_2O(g).$$

What volume of CO_2 is produced at STP by the complete combustion of 1·0 g of heptane? (A_r H = 1; C = 12)

A 0·224 dm^3 **B** 1·57 dm^3 **C** 1·79 dm^3 **D** 2·46 dm^3

J8-2 40 D | The volume of CO_2 (at STP) evolved during the combustion of x g of an alkane of general formula C_nH_{2n+2} is (given A_r: H = 1, C = 12, O = 16)

A $\frac{44x}{14n + 2}$ dm^3.

B $\frac{nx}{14n + 2}$ dm^3.

C $\frac{22.4x}{44}$ dm^3.

D $\frac{22.4nx}{14n + 2}$ dm^3.

E $\frac{22.4nx}{44}$ dm^3.

The next two items refer to the following information

Sodium hydroxide is manufactured by electrolysis of a solution of sodium chloride in a mercury cell. Sodium metal forms at the cathode of the cell and combines with mercury to form an amalgam. Treatment of the amalgam with water produces sodium hydroxide and hydrogen.

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

In one such process, sodium reacts completely with water at the rate of 2.3 g s^{-1}.

(A_r Na = 23, molar volume of H_2 at STP = 22.4 dm^3 mol^{-1})

J8-3 50 B | The amount of NaOH formed by the process in one second is

A 0.05 mol. **B** 0.10 mol. **C** 0.20 mol. **D** 0.23 mol.

J8-4 40 A | The rate of production of hydrogen gas at STP, in dm^3 s^{-1}, is

A 1.12. **B** 2.24. **C** 4.48. **D** 11.2.

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J8-5 Carbon dioxide gas at STP is passed through a solution of calcium hydroxide at the rate of 20 $dm^3\ s^{-1}$
60 for four minutes. If the carbon dioxide reacts according the following equation
B

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

the mass of calcium carbonate (M_r = 100) produced will be
(molar volume of carbon dioxide at STP = 22.4 $dm^3\ mol^{-1}$)

A $\frac{22.4 \times 100}{20 \times 4 \times 60}$ g.

B $\frac{20 \times 4 \times 60 \times 100}{22.4}$ g.

C $\frac{4 \times 22.4 \times 100}{20 \times 60}$ g.

D $\frac{20 \times 100}{4 \times 22.4}$ g.

The next two items refer to the following information

Iron pyrites, FeS_2 (M_r = 119.8), can be used as a source of iron. The ore is first roasted in order to convert the sulfide to an oxide in the reaction

$$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$$

The sulfur dioxide produced as a by-product is oxidized to sulfur trioxide and reacted with water to give sulfuric acid (M_r = 98), as follows

$$SO_2 + \tfrac{1}{2}O_2 \rightarrow SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

(molar volume of a gas at STP = 22.4 $dm^3\ mol^{-1}$)

J8-6 What is the maximum volume of sulfur dioxide gas at STP which can be produced from 2000 kg of
60 iron pyrites?
B

A $\frac{2000 \times 1000 \times 22.4}{119.8}$ dm^3

B $\frac{2 \times 2000 \times 1000 \times 22.4}{119.8}$ dm^3

C $\frac{2000 \times 1000 \times 22.4}{119.8 \times 1000}$ dm^3

D $\frac{2000 \times 1000 \times 22.4}{2 \times 119.8}$ dm^3

J8-7 What volume of pure sulfuric acid (density 1.8 $g\ cm^{-3}$) could be prepared from 2000 kg of iron pyrites?
40
A

A $\frac{2 \times 2000 \times 1000 \times 98}{119.8 \times 1.8}$ cm^3

B $\frac{2 \times 2000 \times 1000 \times 1.8}{119.8 \times 98}$ cm^3

C $\frac{2000 \times 1000 \times 98}{119.8 \times 1.8}$ cm^3

D $\frac{4 \times 2000 \times 1.8 \times 98}{119.8 \times 1000}$ cm^3

J8-8 Potassium chlorate, $KClO_3$, is used in percussion caps and in igniters for explosives. It decomposes
60 readily, according to the equation
D

$$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$$

32.6 g of potassium chlorate is completely decomposed into potassium chloride and oxygen.

The volume of oxygen formed, measured at STP, is (given M_r: $KClO_3$ = 122.6, O_2 = 32)

A $\frac{2}{3} \times \frac{32.6}{122.6} \times 22.4\ dm^3$.

B $\frac{2}{3} \times \frac{32.6}{122.6} \times 32\ dm^3$.

C $\frac{3}{2} \times \frac{122.6}{32.6} \times 32\ dm^3$.

D $\frac{3}{2} \times \frac{32.6}{122.6} \times 22.4\ dm^3$.

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J8-9 30 C

A sample of concentrated sulfuric acid contains 60% by mass of pure H_2SO_4. It reacts with sulfur according to the equation

$$S + 2H_2SO_4 \rightarrow 3SO_2 + 2H_2O.$$

The mass of concentrated H_2SO_4 solution needed to yield 2.24 dm^3 of SO_2 gas, measured at STP, is (given M_r H_2SO_4 = 98, molar volume of SO_2 at STP = 22.4 $dm^3\ mol^{-1}$)

A $\frac{2.24}{22.4} \times \frac{3}{2} \times 98 \times \frac{100}{60}$ g.

B $\frac{2.24}{22.4} \times \frac{3}{2} \times 98 \times \frac{60}{100}$ g.

C $\frac{2.24}{22.4} \times \frac{2}{3} \times 98 \times \frac{100}{60}$ g.

D $\frac{2.24}{22.4} \times \frac{2}{3} \times 98 \times \frac{60}{100}$ g.

The next two items refer to the following information

2·45 g of pure potassium chlorate ($KClO_3$) was quantitatively decomposed to produce potassium chloride (KCl) and oxygen. The potassium chloride was dissolved in water and treated with a 0·2 M silver nitrate solution ($AgNO_3$) producing a precipitate of silver chloride.
(A_r N = 14, O = 16; K = 39; Cl = 35·5; Ag = 108)

J8-10 50 B

The volume of oxygen released from 2·45 g of $KClO_3$ at STP is

A 0·02 × 22·4 dm^3.

B 0·03 × 22·4 dm^3.

C 0·04 × 22·4 dm^3.

D 0·06 × 22·4 dm^3.

J8-11 50 B

The volume of silver nitrate solution required for the complete reaction of the potassium chloride solution is

A $\frac{0 \cdot 2 \times 1000}{0 \cdot 02}$ cm^3.

B $\frac{0 \cdot 02 \times 1000}{0 \cdot 2}$ cm^3.

C $\frac{0 \cdot 2 \times 1000}{0 \cdot 04}$ cm^3.

D $\frac{0 \cdot 02 \times 1000}{0 \cdot 4}$ cm^3.

J8-12 30 E

(Molar volume of a gas = 22.4 $dm^3\ mol^{-1}$ at STP)
It is desired to determine the concentration and volume strength of a commercial sample of an aqueous solution of hydrogen peroxide, H_2O_2.
H_2O_2 decomposes according to the equation

$$H_2O_2(aq) \rightarrow H_2O(l) + \frac{1}{2}O_2(g)$$

The volume strength means the volume of oxygen at STP produced per unit volume of solution. In this particular case, 1 dm^3 of the aqueous H_2O_2 solution decomposed and produced 0.112 dm^3 of O_2 at STP. Which of the following is correct?

The aqueous solution of H_2O_2 had

A a concentration of 0.01 mol dm^{-3}, and a volume strength of 0.224.

B a concentration of 0.005 mol dm^{-3}, and a volume strength of 0.112.

C a concentration of 0.05 mol dm^{-3}, and a volume strength of 0.224.

D a concentration of 0.001 mol dm^{-3}, and a volume strength of 0.224.

E a concentration of 0.01 mol dm^{-3}, and a volume strength of 0.112.

J8-13 30 C

A white powder used to soften water was believed to consist of hydrated sodium carbonate, $Na_2CO_3.H_2O$. 1.24 g of the powder was mixed with 30 cm^3 of a nitric acid solution believed to be 1.00 M. The carbon dioxide produced was collected and occupied a volume at STP of 260 cm^3 instead of the expected 224 cm^3. This discrepancy could be explained by assuming that the
(M_r: $Na_2CO_3.H_2O$ = 124, $NaHCO_3$ = 84, HNO_3 = 63, NaCl = 58.5)

A acid was a little more concentrated than 1.00 M.

B sodium carbonate had absorbed water from the atmosphere, partially forming the decahydrate, $Na_2CO_3.10H_2O$.

C sodium carbonate contained an appreciable amount of sodium hydrogen carbonate.

D sodium carbonate contained some sodium chloride as impurity.

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J8-14 One method for the industrial production of ethyne gas, C_2H_2, involves the action of water on calcium carbide, CaC_2, according to the equation:
70
B

$$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$$

The mass, in gram, of calcium carbide (M_r = 64) required to generate 32 dm^3 of ethyne at 1.0×10^5 Pa pressure and 364 K when reacted with excess water, is (given R = 8.31 J K^{-1} mol^{-1})

A $\frac{32 \times 10^{-3} \times 364 \times 64}{8.31 \times 1.0 \times 10^5}$.

B $\frac{32 \times 10^{-3} \times 1.0 \times 10^5 \times 64}{8.31 \times 364}$.

C $\frac{32 \times 10^{-3} \times 8.31 \times 364 \times 64}{1.0 \times 10^5}$.

D $\frac{32 \times 64}{22.4}$.

The next three items refer to the following information

Gaseous hydrogen sulfide burns in oxygen according to

$$2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$$

(A_r: H = 1, O = 16, S = 32)

J8-15 What mass of oxygen would be used up by the combustion of 5 g of H_2S?
60
E

A $\frac{2}{3} \times \frac{34}{5} \times \frac{1}{32}$ g

B $\frac{2}{3} \times \frac{5}{34} \times \frac{32}{1}$ g

C $\frac{3}{2} \times \frac{5}{34} \times \frac{16}{1}$ g

D $\frac{3}{2} \times \frac{5}{34} \times \frac{1}{32}$ g

E $\frac{3}{2} \times \frac{5}{34} \times \frac{32}{1}$ g

J8-16 The volume occupied by 5 g of H_2S at 0.10 atm pressure and 25 °C would be (given the gas constant R = 8.31 J K^{-1} mol^{-1}; 1 atm = 101325 Pa)
80
D

A $\frac{34}{5} \times \frac{8.31}{1} \times \frac{298}{1} \times \frac{1}{0.1 \times 101325}$ m^3

B $\frac{5}{34} \times \frac{8.31}{1} \times \frac{25}{1} \times \frac{1}{0.1 \times 101325}$ m^3

C $\frac{5}{34} \times \frac{8.31}{1} \times \frac{25}{1} \times \frac{0.1 \times 101325}{1}$ m^3

D $\frac{5}{34} \times \frac{8.31}{1} \times \frac{298}{1} \times \frac{1}{0.1 \times 101325}$ m^3

E $\frac{5}{34} \times \frac{8.31}{1} \times \frac{298}{1} \times \frac{0.1 \times 101325}{1}$ m^3

J8-17 If the products of reaction of 3.4 g of H_2S with oxygen are dissolved in 1 dm^3 of 1.0 M NaOH solution, and react according to the equation
40
D

$$SO_2(g) + 2OH^-(aq) \rightarrow SO_3^{2-}(aq) + H_2O(l),$$

the final hydroxide ion concentration would be

A 0.20 M. **B** 0.40 M. **C** 0.60 M. **D** 0.80 M. **E** 0.90 M.

J9 Mass-gas pressure relationships

J9-1 Ammonium chloride, NH_4Cl, dissociates on heating according to:
20
D

$$NH_4Cl(s) \rightarrow NH_3(g) + HCl(g)$$

0.053 g of dry NH_4Cl is placed in a dry vessel of volume 500 cm^3. The vessel is evacuated, and heated to 500 °C, when the NH_4Cl is completely dissociated into $NH_3(g)$ and $HCl(g)$. The total pressure in the vessel, in Pa, would then be
(given M_r NH_4Cl = 53; R = 8.31 J K^{-1} mol^{-1})

A $\frac{0.053}{53} \times \frac{8.31 \times 773}{500 \times 10^{-6}}$.

B $\frac{2 \times 0.053}{53} \times \frac{500 \times 10^{-6}}{8.31 \times 773}$.

C $\frac{2 \times 0.053}{53} \times \frac{8.31 \times 773}{500}$.

D $\frac{2 \times 0.053}{53} \times \frac{8.31 \times 773}{500 \times 10^{-6}}$.

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K HEAT OF REACTION

K1 Exothermic and endothermic reactions

K1-1 50 D

A reaction is endothermic if

A heat energy is released during the course of the reaction.
B the reaction proceeds more rapidly at high temperatures.
C the value of the equilibrium constant decreases with increasing temperature.
D the energy of the products is greater than that of the reactants.

K1-2 80 C

Consider an exothermic reaction summarized as

reactants $\rightarrow$ products.

There is an energy *difference* between the reactant and product molecules. Which one of the following best summarizes the main source of this energy difference between the reactants and products?

	reactants		*products*
A	kinetic energy	is converted into	chemical bond energy
B	kinetic energy	is converted into	kinetic energy
C	chemical bond energy	is converted into	kinetic energy
D	chemical bond energy	is converted into	chemical bond energy

K1-3 50 D

A beaker contains 100 cm^3 of water and is thermally insulated from its surroundings. 0.100 mol of solid potassium nitrate is added to the water and stirred until it has all dissolved. The water was initially at a temperature of 16.00 °C. After all the potassium nitrate has dissolved the temperature is 7.90 °C.

The temperature change is caused by heat energy

A absorbed from the surroundings into the beaker and water.
B lost from the beaker and water to the surroundings.
C evolved in the solution process.
D absorbed in the solution process.

K1-4 70 C

Potassium chloride crystals dissolve readily in water, according to the equation

$$KCl(s) \rightarrow K^+(aq) + Cl^-(aq) \qquad \Delta H = +17 \text{ kJ mol}^{-1}$$

The dissolving process takes place because

A the KCl crystals are unstable.
B all systems move spontaneously from low to high energy states.
C the system becomes more disordered.
D the energy of the hydrated ions is lower than the energy of the ions in the crystal lattice.

K2 Uses of exothermic reactions

K2-1 40 C

In Victoria, brown coal deposits will be able to supply the State's electrical needs for many years to come.
In a coal burning power station,

A all the chemical bond energy released from the coal is converted into electrical energy.
B all the heat energy released from the coal is converted into electrical energy.
C all the chemical bond energy released from the coal is converted into either electrical or heat energy.
D all the heat energy released from the coal is converted into either electrical or chemical bond energy.

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K2-2 70 A

Which of the following reactions would be least likely to occur in the furnace of a fossil fuel power station?

A $2H_2 + O_2 \rightarrow 2H_2O$

B $C + O_2 \rightarrow CO_2$

C $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

D $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

K2-3 30 D

Which one of the following processes is **not** involved in the burning of petrol in a car engine?

A reduction

B an exothermic reaction

C oxidation

D conversion of matter to energy

K3 Temperature changes during reactions

The next two items refer to the following information

100.0 cm^3 of water containing 0.2 mol of hydrochloric acid at 10.10 °C is added to 100.0 cm^3 of water containing 0.2 mol of sodium hydroxide at 10.10 °C in a thermally insulated container. The final temperature of the mixture is found to be 11.50 °C.

K3-1 40 A

If 200 cm^3 of water containing 0.2 mol of hydrochloric acid at 10.10 °C were added to 200 cm^3 of water containing 0.2 mol of sodium hydroxide at 10.10 °C in a thermally insulated container, the amount of heat energy released

A would be the same in the second as that released in the first mixture.

B would be larger in the second than that released in the first mixture.

C would be smaller in the second than that released in the first mixture.

D cannot be determined from the data given.

K3-2 20 C

The final temperature of the second mixture will be

A 5.05 °C. **B** 5.75 °C. **C** 10.80 °C. **D** 11.50 °C. **E** 13.00 °C.

K4 Units of energy

K4-1 20 D

One kilojoule of heat

A is produced when a current of 96,500 coulomb flows for one second through a resistance.

B is sufficient to increase the temperature of one gram of pure water by 1 K.

C is needed to increase the temperature of one kilogram of pure water by 1 K.

D is produced when a current of one ampere flows for 1000 seconds through a resistance the ends of which differ in potential by one volt.

K5 Enthalpy change

K5-1 60 A

The sign of ΔH for the process

$$Al_2O_3(s) \rightarrow Al_2O_3(l)$$

is

A positive and the reaction is endothermic.

B positive and the reaction is exothermic.

C negative and the reaction is endothermic.

D negative and the reaction is exothermic.

K5-2 30 B

Which one of the following processes has the sign of its enthalpy change different from the rest?

A $Cl_2(s) \rightarrow Cl_2(g)$

B $Cl(g) + e^- \rightarrow Cl^-(g)$

C $Cl(g) \rightarrow Cl^+(g) + e^-$

D $Cl_2(g) \rightarrow 2Cl(g)$

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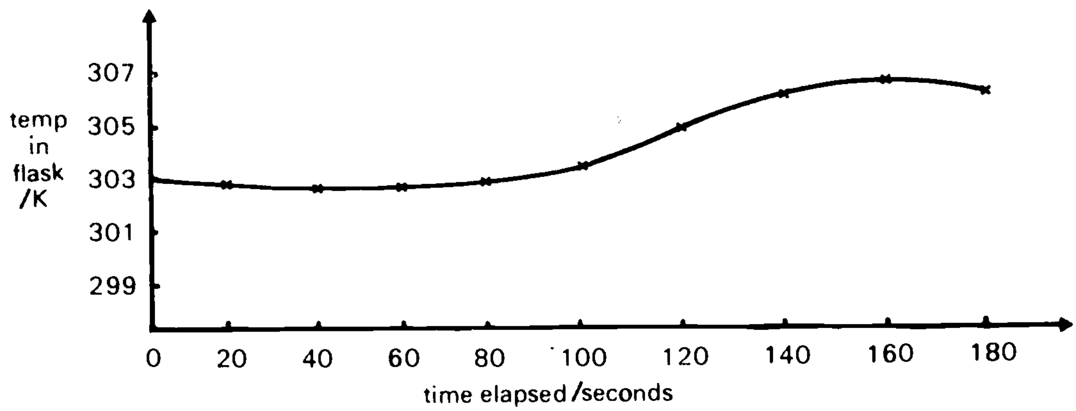
The next two items refer to the following information.

150 cm^3 of water at 303 K was placed in an insulated flask, and the temperature measured at 20 second intervals for 3 minutes. The results are shown on the graph below. After 60 seconds, 0·1 mol of the compound NaX was added to the water.
Room temperature was 293 K throughout the experiment.



K5-3 The solution process $NaX(s) + aq \rightarrow Na^+(aq) + X^-(aq)$ is
90 **A** exothermic. **C** endergonic.
A **B** endothermic. **D** thermoneutral.

K5-4 The sign for ΔH in the above reaction is
90 **A** negative, as the system gradually gains heat from its surroundings.
D **B** positive, as the water tends to gain energy.
C positive, as the solid tends to lose energy to the water.
D negative, as the system produces heat which it gradually loses to its surroundings.

K5-5 The equation below represents the solution of sodium thiosulphate in excess water.
80
$$Na_2S_2O_3(s) + aq \rightarrow 2Na^+(aq) + S_2O_3^{2-}(aq) \qquad \Delta H = +7{\cdot}15\ kJ\ mol^{-1}$$
C When 0·010 mol of sodium thiosulphate is dissolved in 100 cm^3 of pure water in a thermally insulated container,
A the water will become warmer due to the reaction.
B the water will remain at the same temperature but heat will be given off to the surroundings.
C the water will become colder due to the reaction.
D the water will remain at the same temperature but heat will be absorbed from the surroundings.

K5-6 HCl and O_2 react according to the following equation, forming H_2O and Cl_2.
50
$$4HCl(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2Cl_2(g) \qquad \Delta H = -113\ kJ\ mol^{-1}$$
A If H_2O gas and Cl_2 gas were mixed in a thermally insulated vessel, the reaction that occurs would be
A endothermic and the temperature of the gas mixture would fall.
B endothermic and the temperature of the gas mixture would rise.
C exothermic and the temperature of the gas mixture would fall.
D exothermic and the temperature of the gas mixture would rise.

K5-7 How much heat is released on burning 1 mol (28 g) of CO?
60
$$2CO(g) + O_2(g) \rightarrow 2CO_2(g); \qquad \Delta H = -564\ kJ\ mol^{-1}$$
A **A** 564/2 kJ **C** 564 kJ
B 564 × 28 kJ **D** 564 × 2 kJ

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K5-8 60 D

Ozone, one of the allotropic forms of oxygen, occurs in moderate concentrations in the upper atmosphere. It decomposes to form oxygen thus:

$$2O_3 \rightarrow 3O_2 \qquad \Delta H = -285 \text{ kJ mol}^{-1}$$

What amount of heat is released when 10^{-6} mol of ozone molecules decomposes?

A $\frac{2}{285 \times 10^{-6}}$ kJ

B $\frac{285 \times 10^{-6}}{3}$ kJ

C $\frac{285 \times 2}{10^{-6}}$ kJ

D $\frac{285 \times 10^{-6}}{2}$ kJ

E $2 \times 285 \times 10^{-6}$ kJ

K5-9 50 A

2×10^{23} atoms of carbon react with hydrogen to produce ethyne.

$$2C(s) + H_2(g) \rightarrow C_2H_2(g) \qquad \Delta H = +54 \text{ kJ mol}^{-1}$$

The heat absorbed would be approximately

A 9 kJ. B 18 kJ. C 27 kJ. D 36 kJ. E 54 kJ.

K5-10 60 A

How much heat is evolved when 13 g of acetylene (C_2H_2) is burnt in air according to the equation

$$2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l) \qquad \Delta H = -2610 \text{ kJ mol}^{-1}$$

(A_r C = 12, H = 1)

A 652·5 kJ

1305 kJ

C 2610 kJ

D 5220 kJ

The next two items refer to the following information.

Nitroglycerine (M_r = 227) decomposes explosively according to the equation

$$4C_3H_5(NO_3)_3(l) \rightarrow 12CO_2(g) + 10H_2O(g) + 6N_2(g) + O_2(g) \qquad \Delta H = -1810 \text{ kJ mol}^{-1}$$

The reaction can produce temperatures around 3000 °C.

K5-11 40 D

What volume of gas, measured at 3000 °C and 101325 Pa pressure, would be produced by the decomposition of 22.7 g of the explosive (given the molar volume of a gas at STP = 22.4 dm^3 mol^{-1})?

A $\frac{22.7 \times 19 \times 22.4 \times 3273}{227 \times 4 \times 273}$ dm^3

B $\frac{22.7 \times 29 \times 22.4 \times 273}{227 \times 4 \times 3273}$ dm^3

C $\frac{227 \times 29 \times 22.4 \times 273}{22.7 \times 4 \times 3273}$ dm^3

D $\frac{22.7 \times 29 \times 22.4 \times 3273}{227 \times 4 \times 273}$ dm^3

E $\frac{22.7 \times 4 \times 22.4 \times 3273}{227 \times 29 \times 273}$ dm^3

K5-12 30 A

How much heat is released by the decomposition of 22.7 g of nitroglycerine?

A 45 kJ B 181 kJ C 724 kJ D 1810 kJ

K5-13 40 D

Methanol burns in air according to the equation

$$2CH_3OH(g) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)$$

If 67.6 kJ of heat was evolved when 0.10 mol of methanol was burnt, ΔH for the equation would be

A -6.76 kJ mol^{-1}.

B -13.52 kJ mol^{-1}.

C -676 kJ mol^{-1}.

D -1352 kJ mol^{-1}.

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K5-14 | 70 | D

The combustion of the fuel gas butane (C_4H_{10}) proceeds according to the equation

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l) \qquad \Delta H = -5760 \text{ kJ mol}^{-1}$$

The mass of butane ($M_r = 58$) which must be burned in order to produce 1·0 kJ of heat according to the equation given is

A $\frac{1 \cdot 0}{5760} \times 58$ g.

B $\frac{1 \cdot 0}{5760} \times \frac{58}{2}$ g.

C $5760 \times 2 \times 58$ g.

D $\frac{1 \cdot 0}{5760} \times 2 \times 58$ g.

E $\frac{5760}{2} \times 1 \cdot 0 \times 58$ g.

K5-15 | 50 | B

LP gas, which is used as a fuel in camping stoves, consists mainly of propane, C_3H_8. Propane burns in oxygen according to the equation

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \qquad \Delta H = -2217 \text{ kJ mol}^{-1}$$

A particular camping stove using propane fuel had a heat output of 22.17 kJ per minute. Each minute that the camping stove operates
(A_r: O = 16, C = 12, H = 1)

A 0.05 g of O_2 is consumed.

B 0.44 g of C_3H_8 is consumed.

C 1.8×10^{24} molecules of CO_2 are produced.

D 0.72 kg of H_2O is produced.

K5-16 | 50 | A

0·5 mol of CO and 0·4 mol of O_2 were placed in a sealed vessel and the temperature was held constant until equilibrium was attained according to the equation

$$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g) \qquad \Delta H = -564 \text{ kJ mol}^{-1}$$

If 0·3 mol of O_2 remains at equilibrium, the thermal energy released would be

A $0 \cdot 1 \times 564$ kJ

B $0 \cdot 2 \times 564$ kJ

C $0 \cdot 3 \times 564$ kJ

D $0 \cdot 4 \times 564$ kJ

K5-17 | 60 | B

When solid sodium nitrate is dissolved in pure water, the reaction may be represented by the equation

$$NaNO_3(s) + aq \rightarrow Na^+(aq) + NO_3^-(aq) \qquad \Delta H = +21 \text{ kJ mol}^{-1}$$

0·01 mol of solid $NaNO_3$ is dissolved in 100 cm^3 of pure water.
The quantity of heat that would need to be absorbed from the surroundings, in order to return the solution to the original temperature, is

A $2 \cdot 1 \times 10^{-2}$ kJ.

B $2 \cdot 1 \times 10^{-1}$ kJ.

C $2 \cdot 1 \times 10^{0}$ kJ.

D $2 \cdot 1 \times 10^{1}$ kJ.

E $2 \cdot 1 \times 10^{2}$ kJ.

The next two items refer to the following information

Thermochemical data for the combustion of a number of fuels are given below.

methanol:	$2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)$	$\Delta H = -1454$ kJ mol^{-1}.
carbon monoxide:	$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$	$\Delta H = -564$ kJ mol^{-1}.
hydrazine:	$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$	$\Delta H = -622$ kJ mol^{-1}.
methane:	$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$	$\Delta H = -890$ kJ mol^{-1}.

K5-18 | 50 | D

Which of the fuels releases the maximum amount of energy per kilogram of fuel when burnt?
(A_r: H = 1, C = 12, N = 14, O = 16)

A CH_3OH **B** CO **C** N_2H_4 **D** CH_4

K5-19 | 50 | D

If one gram of each fuel were completely burnt in air, which fuel would react with the largest amount of oxygen?

A CH_3OH **B** CO **C** N_2H_4 **D** CH_4

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ERIC

K5-20 30 **A**

A space heater burns natural gas at the rate of 1100 dm^3 per hour. If the volume is measured at STP, and natural gas burns according to the equation

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) \qquad \Delta H = -890 \text{ kJ mol}^{-1}$$

how long will the heater take to produce 1 MJ of energy?
(1MJ = 1000 kJ, molar volume of a gas at STP = 22.4 dm^3 mol^{-1})

A $\frac{1000 \times 22.4}{890 \times 1100}$ h

B $\frac{890 \times 22.4}{1000 \times 1100}$ h

C $\frac{1000 \times 890}{22.4 \times 1100}$ h

D $\frac{890 \times 1100}{1000 \times 22.4}$ h

K5-21 50 **D**

A man uses energy at the rate of 2.5 kJ min^{-1}. Assuming his energy to be obtained by the oxidation of glucose (M_r = 180):

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) \qquad \Delta H = -2803 \text{ kJ mol}^{-1}$$

the mass of glucose consumed each minute will be

A $\frac{2.5 \times 180 \times 10^3}{2803}$ g.

B $\frac{2803 \times 180}{2.5}$ g.

C $\frac{2803 \times 180 \times 10^3}{2.5}$ g.

D $\frac{2.5 \times 180}{2803}$ g.

K5-22 70 **D**

For the reaction $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \qquad \Delta H = -56 \text{ kJ mol}^{-1}$
When 10 cm^3 of 0·25 M HCl solution is reacted with 20 cm^3 of 0·15 M NaOH solution, the heat change occurring has the value

A 56 J.
B 5·5 × 56 J.
C 3 × 56 J.
D 2·5 × 56 J.
E 0·5 × 56 J.

K5-23 40 **D**

300 cm^3 of 2 M HCl is mixed with 200 cm^3 of 2 M KOH in a thermally insulated container. They react according to the equation

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l) \qquad \Delta H = -56 \text{ kJ mol}^{-1}.$$

The temperature of the solutions was 20 °C at the instant they were mixed.

If 2.1 kJ is required to raise the temperature of 500 cm^3 of water every 1 °C, the final temperature of the water would be about

A 10 °C. B 15 °C. C 20 °C. D 30 °C. E 35 °C.

K5-24 40 **A**

Given the equation

$$H_3O^+(aq) + OH^-(aq) \rightleftharpoons 2H_2O(l) \qquad \Delta H = -56 \text{ kJ mol}^{-1}$$

the heat evolved when 50 cm^3 of 0.20 M $Ba(OH)_2$ is mixed with 50 cm^3 of 0.30 M HCl is

A $\frac{50}{1000} \times 0.30 \times 56$ kJ.

B $\frac{50}{1000} \times 0.30 \times 2 \times 56$ kJ.

C $\frac{50}{1000} \times 0.20 \times 56$ kJ.

D $\frac{50}{1000} \times 0.20 \times \frac{56}{2}$ kJ.

E $\frac{50}{1000} \times 0.20 \times 2 \times 56$ kJ.

K5-25 20 **A**

The reaction between dilute sulfuric acid and sodium hydroxide solution is represented by

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l) \qquad \Delta H = -56 \text{ kJ mol}^{-1}$$

20 cm^3 of 2 M sulfuric acid was mixed with 30 cm^3 of 2 M sodium hydroxide solution. The energy released would be

A 30 × 2 × 56 J.
B 20 × 2 × 56 J.
C 2 × 20 × 2 × 56 J.
D $\frac{1}{2}$ × 20 × 2 × 56 J.

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K5-26 70 **B**

Consider the following thermochemical equations.

$CaSO_4(s) + aq \rightarrow Ca^{2+}(aq) + SO_4^{2-}(aq) \qquad \Delta H = -66.5 \text{ kJ mol}^{-1}$

$CaSO_4.5H_2O(s) + aq \rightarrow Ca^{2+}(aq) + SO_4^{2-}(aq) + 5H_2O(l) \qquad \Delta H = +11.7 \text{ kJ mol}^{-1}$

A mixture of solid $CaSO_4$ and $CaSO_4.5H_2O$ was added to a volume of water in a thermally insulated vessel, and no temperature change occurred. If the mixture contained 2.0 mol of $CaSO_4$, the amount of $CaSO_4.5H_2O$ present in the mixture was

A $\frac{2.0 \times 11.7}{66.5}$ mol.

B $\frac{2.0 \times 66.5}{11.7}$ mol.

C $\frac{1 \times 11.7}{2.0 \times 66.5}$ mol.

D $\frac{1 \times 66.5}{2.0 \times 11.7}$ mol.

The next three items refer to the following information

In Papua New Guinea a farmer uses excreta from his pigs to produce 30 m^3 of methane at STP per day. When burnt, the methane supplies sufficient energy for two families.

The combustion reaction is represented by

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) \qquad \Delta H = -890 \text{ kJ mol}^{-1}$$

(molar volume of a gas at STP = 22.4 $dm^3\ mol^{-1}$)

K5-27 30* **B**

If a day's yield of methane were reacted completely with 60 m^3 of oxygen and the gases produced were brought to STP conditions, the volume would be approximately

A 15 m^3. **B** 30 m^3. **C** 60 m^3. **D** 90 m^3.

K5-28 60 **D**

The thermal energy produced per day is

A $\frac{30 \times 10^3 \times 890}{2 \times 22.4}$ kJ.

B $\frac{30 \times 890}{22.4}$ kJ.

C $\frac{22.4 \times 890}{30}$ kJ.

D $\frac{30 \times 10^3 \times 890}{22.4}$ kJ.

K5-29 50 **B**

334 kJ of heat energy is required in order to boil a 1 kg mass of water which is initially at a temperature of 20 °C. What volume of methane gas, measured at STP, must be burnt to obtain sufficient energy to boil the water (assuming the energy transfer is 100% efficient)?

A $\frac{890}{334 \times 22.4 \times 10^{-3}}$ m^3

B $\frac{334 \times 22.4 \times 10^{-3}}{890}$ m^3

C $\frac{334}{890 \times 22.4 \times 10^{-3}}$ m^3

D $\frac{890 \times 22.4 \times 10^{-3}}{334}$ m^3

K5-30 90 **D**

For the reaction $H_2(g) + X_2(g) \rightarrow 2HX(g)$ $\Delta H = -110 \text{ kJ mol}^{-1}$

ΔH for the reaction $HX(g) \rightarrow \frac{1}{2}H_2(g) + \frac{1}{2}X_2(g)$ is

A -220 kJ mol^{-1}. **B** -110 kJ mol^{-1}. **C** -55 kJ mol^{-1}. **D** $+55 \text{ kJ mol}^{-1}$. **E** $+110 \text{ kJ mol}^{-1}$.

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K5-31
50
C

Ammonia is manufactured commercially by reacting nitrogen and hydrogen together at high temperature and pressure, according to the following equation

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

When 1.0 mol of ammonia is produced in this way, 46 kJ of heat energy is produced.

When 2.0 mol of ammonia completely dissociates to form nitrogen and hydrogen, the amount of heat energy associated with the reaction is

A 23 kJ, and the reaction is endothermic.
B 23 kJ and the reaction is exothermic.
C 92 kJ, and the reaction is endothermic.
D 92 kJ, and the reaction is exothermic.

K5-32
60
A

The combustion of butane can be represented by the thermochemical equation

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l) \qquad \Delta H = -5770 \text{ kJ mol}^{-1}$$

The formation of 2 mol of butane from carbon dioxide and water involves

A absorption of 5770 kJ of heat.
B absorption of 11540 kJ of heat.
C release of 5770 kJ of heat.
D release of 11540 kJ of heat.

K6 Calorimetry

K6-1
30
A

A calorimeter has a calibration factor of 450 J °C^{-1}. When 0.01 mol of a salt is dissolved in water within this calorimeter, there is a temperature rise of 3.0 °C. The energy released during the dissolution process was

A 450×3.0 J.
B $\frac{450 \times 3.0}{0.01}$ J.
C $450 \times 3.0 \times 0.01$ J.
D $\frac{450}{3.0 \times 0.01}$ J.

K6-2
40
C

0.020 mol of solid KOH was added to a calorimeter containing 250 cm^3 of water. The temperature rose from 18.64 °C to 19.58 °C as the solid dissolved. If the calibration factor of the calorimeter was 1200 J K^{-1}, ΔH for the reaction

$$KOH(s) + aq \rightarrow K^+(aq) + OH^-(aq)$$

has a magnitude of

A $\frac{1200 \times 273.94}{0.020}$ J mol^{-1}.
B $\frac{1200}{0.94 \times 0.020}$ J mol^{-1}.
C $\frac{1200 \times 0.94}{0.020}$ J mol^{-1}.
D $1200 \times 0.94 \times 0.020$ J mol^{-1}.

K6-3
40
A

A calorimeter has a calibration factor of 530 J K^{-1}. What temperature rise would be expected if a volume of 30 cm^3 of methane measured at STP is burnt in the calorimeter according to the following equation?

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) \qquad \Delta H = -889 \text{ kJ mol}^{-1}$$

(molar volume of methane at STP = 22400 cm^3 mol^{-1})

A $\frac{30}{22400} \times \frac{889}{530} \times \frac{1000}{1}$ K
B $\frac{22400}{30} \times \frac{530}{889} \times \frac{1}{1000}$ K
C $\frac{30}{22400} \times \frac{889}{530}$ K
D $\frac{30}{22400} \times \frac{530}{889} \times \frac{1000}{1}$ K
E $\frac{22400}{30} \times \frac{889}{530} \times \frac{1000}{1}$ K

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K7 Thermochemical cycles

K7-1 When graphite and diamond burn, they react according to the following equations
40
B

$$C\ (graphite) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H = -393\ kJ\ mol^{-1}$$

$$C\ (diamond) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H = -395\ kJ\ mol^{-1}$$

On the basis of the above data, when 1 mol of graphite is converted to 1 mol of diamond under the same conditions,

A 2 kJ of heat are evolved to the surroundings.
B 2 kJ of heat are absorbed from the surroundings.
C 788 kJ of heat are absorbed from the surroundings.
D 788 kJ of heat are evolved to the surroundings.

K7-2 Given the following thermochemical data:
20
D

$$2Rb + \tfrac{1}{2}O_2 \rightarrow Rb_2O \qquad \Delta H = -330\ kJ\ mol^{-1}$$

$$2Rb + O_2 \rightarrow Rb_2O_2 \qquad \Delta H = -426\ kJ\ mol^{-1}$$

$$Rb + O_2 \rightarrow RbO_2 \qquad \Delta H = -264\ kJ\ mol^{-1}$$

which of the following reactions is the **least** exothermic?

A $4Rb + O_2 \rightarrow 2Rb_2O$
B $2Rb + O_2 \rightarrow Rb_2O_2$
C $2Rb + 2O_2 \rightarrow 2RbO_2$
D $2Rb_2O + O_2 \rightarrow 2Rb_2O_2$
E $Rb_2O + \tfrac{3}{2}O_2 \rightarrow 2RbO_2$

The next three items refer to the following information

Oxygen gas and solid iron may react in three different ways, as shown in the equations below.

$$Fe(s) + \tfrac{1}{2}O_2(g) \rightarrow FeO(s), \qquad \Delta H = -272\ kJ\ mol^{-1}$$

$$3Fe(s) + 2O_2(g) \rightarrow Fe_3O_4(s), \qquad \Delta H = -1118\ kJ\ mol^{-1}$$

$$2Fe(s) + \tfrac{3}{2}O_2(g) \rightarrow Fe_2O_3(s), \qquad \Delta H = -824\ kJ\ mol^{-1}$$

K7-3 Three equal amounts of iron are reacted with oxygen gas, as shown by the following equations:
50
C

I $3Fe(s) + \tfrac{3}{2}O_2(g) \rightarrow 3FeO(s)$

II $3Fe(s) + 2O_2(g) \rightarrow Fe_3O_4(s)$.

III $3Fe(s) + \tfrac{9}{4}O_2(g) \rightarrow \tfrac{3}{2}Fe_2O_3(s)$.

Which of the above reactions is the most exothermic?

A I   **B** II   **C** III

K7-4 The ΔH for the reaction represented by the equation
40
B

$3FeO(s) + \tfrac{1}{2}O_2(g) \rightarrow Fe_3O_4(s)$, is equal to

A $(3 \times 1118) - (272)\ kJ\ mol^{-1}$.
B $(3 \times 272) - (1118)\ kJ\ mol^{-1}$.
C $3 \times (272 - 1118)\ kJ\ mol^{-1}$.
D $(1118) - (3 \times 272)\ kJ\ mol^{-1}$.

K7-5 Carbon monoxide can act at a reductant, as shown in the following equation:
30
A

$$CO(g) + \tfrac{1}{2}O_2(g) \rightarrow CO_2(g), \qquad \Delta H = -282\ kJ\ mol^{-1}$$

Carbon monoxide is used in the blast furnace for the production of iron from $Fe_2O_3(s)$. The energy change for the reaction of 1 mol of $Fe_2O_3(s)$ with CO(g) is

A $(824) - (3 \times 282)$ kJ.
B $(2 \times 824) - (3 \times 282)$ kJ.
C $(824) - (282)$ kJ.
D $(2 \times 824) - (282)$ kJ.

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The next three items refer to the following information

(i) $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$; $\Delta H = -564$ kJ mol^{-1}

(ii) $CH_3OH(g) + \frac{3}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$; $\Delta H = -676$ kJ mol^{-1}

(iii) $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$; $\Delta H = -484$ kJ mol^{-1}

(iv) $CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$; $\Delta H = x$ kJ mol^{-1}

K7-6 70 **A**

How much heat is released on burning 1 mol (28 g) of CO?

A 564/2 kJ
B (564 × 28) kJ
C 564 kJ
D (564 × 2) kJ

K7-7 70 C

The numerical value of x, the ΔH for reaction (iv) above, would be

A (−676 + 564 + 484) kJ mol^{-1}.
B (676 + (564/2) + 484) kJ mol^{-1}.
C (676 − (564/2) − 484) kJ mol^{-1}.
D (−676 − (564/2) − 484) kJ mol^{-1}.

K7-8 20* **A**

1 mol of gaseous methanol is burned in excess oxygen and a mixture of 1 mol of CO and 2 mol of H_2 is also burned in excess oxygen.

How does the amount of heat released by the combustion of methanol compare with the heat released by the combustion of the mixture of carbon monoxide and hydrogen?

A More heat is evolved by the CO and $2H_2$.
B More heat is evolved by the CH_3OH.
C The same amount of energy would be evolved in both cases.
D There is insufficient information to decide.

K7-9 30 **B**

Given the information that

$S(s) + O_2(g) \rightarrow SO_2(g)$ $\Delta H = x$ kJ mol^{-1}

$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ $\Delta H = y$ kJ mol^{-1}

$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(l)$ $\Delta H = z$ kJ mol^{-1}

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ $\Delta H = w$ kJ mol^{-1}

the enthalpy change when 1 mol of H_2SO_4 is formed according to the equation

$$S(s) + 2O_2(g) + H_2(g) \rightarrow H_2SO_4(l)$$

is given by

A $(x + y + z + w)$ kJ.
B $(x + \frac{y}{2} + z + \frac{w}{2})$ kJ.
C $(2x + y + 2z + w)$ kJ.
D $(x + y + z) - w$ kJ.
E $(x + \frac{y}{2} + z) - \frac{w}{2}$ kJ.

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L CHEMICAL EQUILIBRIUM

L1 Nature of the equilibrium state

L1-1
90
D

A system is in a state of equilibrium when

A all reaction stops.
B the rate of reaction is negligible.
C the rate of the reverse reaction is insignificant compared to that of the forward reaction.
D the rates of the forward and reverse reactions are equal.

L1-2
40
B

When pure hydrogen iodide is placed in a vessel it will begin to decompose into its elements according to the equation

$$2HI \rightleftharpoons H_2 + I_2$$

Which one of the following statements about the system during the approach to equilibrium is correct?

A The rate of formation of hydrogen iodide is greater than its rate of decomposition.
B The rate of formation of hydrogen iodide is less than its rate of decomposition.
C The rate of formation of hydrogen iodide is equal to its rate of decomposition.
D Not enough evidence is available to judge the relative rates of formation and decomposition of the hydrogen iodide.

L2 The equilibrium constant, K_c

L2-1
80*
C

The equilibrium constant for the reaction

$$NO(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons NO_2(g)$$

is equal to

A $\dfrac{[NO_2]^2}{[NO]^2\,[O_2]}$

B $\dfrac{[NO]\,[O_2]}{[NO_2]}$

C $\dfrac{[NO_2]}{[NO]\,[O_2]^{\frac{1}{2}}}$

D $\dfrac{[NO_2]}{\frac{1}{2}[NO]\,[O_2]}$

E $\dfrac{[NO]\,[O_2]^{\frac{1}{2}}}{[NO_2]}$

L2-2
70
B

A mixture of SO_2 and O_2 at a fixed temperature reacts according to the equation

$$SO_2(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$$

When equilibrium is established, which of the following ratios would be constant, irrespective of the initial concentrations of the gases?

A $\dfrac{[SO_3]}{[SO_2]\,[O_2]}$

B $\dfrac{[SO_3]^2}{[SO_2]^2\,[O_2]}$

C $\dfrac{[SO_3]}{\frac{1}{2}[O_2]\,[SO_2]}$

D $\dfrac{[SO_3]}{[SO_2]\,[O_2]^2}$

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L3 Calculations in equilibrium systems

L3-1 70 **D** A mixture of nitrogen and hydrogen was allowed to achieve equilibrium at a constant temperature. Analysis showed that the mixture contained 2.0 mol N_2, 3.0 mol H_2 and 1.0 mol NH_3. The amount of H_2 originally present was

A $3.0 + (2 \times 2.0)$ mol.
B $3.0 + (\frac{1}{3} \times 2.0)$ mol.
C $3.0 + (\frac{2}{3} \times 1.0)$ mol.
D $3.0 + (\frac{3}{2} \times 1.0)$ mol.

L3-2 20* **A** Consider the reversible reaction

$$A + B \rightleftharpoons 2C + D$$

An equilibrium system consists of 3 mol of A, 2 mol of B, 10 mol of C and 5 mol of D.

The volume is decreased so that 4 mol of B is present when equilibrium is re-established. The amount of C in the new equilibrium state is

A 6 mol. **B** 8 mol. **C** 9 mol. **D** 10 mol. **E** 12 mol.

L3-3 10* **E** When equal volumes of 0.100 M silver nitrate and 0.100 M iron(II) nitrate solution are mixed, it is found that the equilibrium concentration of the silver ion, Ag^+(aq), is 0.001 M.

The equilibrium concentration of Fe^{3+}(aq) will be

A 0.1 M.
B 0.100 − 0.001 M.
C 0.001 M.
D 0.100 + 0.001 M.
E 0.050 − 0.001 M.

L3-4 60 **D** 2.00 mol of HI was placed in a 1 dm^3 container at 600 K. The HI partially decomposed, forming 0.22 mol of H_2 and 0.22 mol of I_2 at equilibrium.

The equilibrium constant for the reaction

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

at 600 K is

A $\frac{1.56}{(0.22)^2}$. **B** $\frac{(1.78)^2}{(0.22)^2}$. **C** $\frac{1.78}{(0.22)^2}$. **D** $\frac{(1.56)^2}{(0.22)^2}$.

The next two items refer to the following information

0.02 mol of SO_2, 0.04 mol of O_2 and 0.07 mol of SO_3 were mixed in a 1 dm^3 vessel and allowed to reach equilibrium according to the equation

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Analysis of the gas mixture showed that 0.03 mol of SO_3 remained.

L3-5 20 **B** The magnitude of the equilibrium constant, K_c, for the reaction at this temperature is

A $\frac{(0.03)^2}{(0.02)^2 \times 0.04}$.
B $\frac{(0.03)^2}{(0.06)^3}$.
C $\frac{(0.04)^2}{(0.05)^2 \times 0.055}$.
D $\frac{(0.03)^2}{(0.03)^2 \times 0.05}$
E $\frac{(0.07)^2}{(0.02)^2 \times 0.04}$

L3-6 60 **C** The mass of the gas mixture at equilibrium, compared to its initial mass, would be

A increased. **B** decreased. **C** unchanged.

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L3-7 40* A

Analysis of a sample of HCl gas at a certain temperature showed that half of the HCl molecules had dissociated into H_2 and Cl_2. If the reaction was at equilibrium, K for the process

$$2HCl \rightleftharpoons H_2 + Cl_2$$

at this temperature is

A $\frac{1}{4}$. B $\frac{1}{2}$. C 1. D 2.

L3-8 30 B

Nitrogen reacts with hydrogen according to the equation

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The magnitude of K_c for this reaction, at 475 °C, is 0.010.
If, in such a system at equilibrium the concentration of NH_3 was 10^{-3} M, and the concentration of N_2 was 10^{-1} M, then the concentration of H_2 was

A 1 M. B 0·1 M. C 0·01 M. D 0·001 M. E 0·0001 M.

L3-9 60 B

1×10^{20} molecules of HI were introduced into a vessel of fixed volume at a particular temperature. After some time there were 6×10^{19} molecules of HI, 2×10^{19} molecules of H_2 and 2×10^{19} molecules of I_2 in the vessel. The temperature was unchanged and, at this temperature, the value of the equilibrium constant for the reaction

$$2HI \rightleftharpoons H_2 + I_2$$

is $K = 2.0$

Which one of the following statements about the system is correct?

A The system is at equilibrium.
B The system is **not** at equilibrium.
C It is impossible to decide whether the system is at equilibrium or not, as the temperature was not stated.
D It is impossible to decide whether the system is at equilibrium or not, as K refers to concentrations expressed in mol dm^{-3}, and the volume of the vessel was not stated.

L3-10 50 A

Hydrogen iodide decomposes according to the equation

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

$$K = 0.006 \text{ at } 250\ °C$$

If equimolar amounts of H_2, I_2 and HI were mixed at this temperature

A some iodine would be reduced.
B the concentration of HI in the mixture would decrease.
C the value of K would increase to 1.0.
D the number of molecules of gas would increase.

L3-11 40 D

The value of the equilibrium constant for the reaction

$$H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g) \qquad \Delta H = +42 \text{ kJ mol}^{-1}$$

is 1.6 at 990 °C.

If equimolar amounts of H_2, CO_2, H_2O and CO which were initially at 990 °C were mixed in a thermally insulated vessel, the temperature of the gases would

A increase and the mass of H_2 would increase
B increase and the mass of H_2 would decrease.
C decrease and the mass of H_2 would increase.
D decrease and the mass of H_2 would decrease.

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L4 Effect of addition of reactants or products

L4-1 80 D

KSCN and $FeCl_3$ solutions are mixed, producing a red solution due to formation of the aquated $FeSCN^{2+}$ ion.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

The intensity of the red colouration could be increased by the addition of

A Ag^{+} ions, which form insoluble AgSCN.
B Sn^{2+} ions, which reduce Fe^{3+} to Fe^{2+}.
C a small volume of water.
D a small quantity of concentrated $Fe(NO_3)_3$ solution.

L4-2 50 B

Naphthalene reacts rapidly with concentrated sulfuric acid at 160 °C to form β-naphthalenesulfonic acid, according to the equation

$$C_{10}H_8 + H_2SO_4 \rightarrow C_{10}H_7SO_3H + H_2O$$

It is desired to convert 0·1 mol of naphthalene as completely as possible into β-naphthalenesulfonic acid at 160 °C.

Which one of the following is most likely to achieve this result?

A react the naphthalene with 0·1 mol of concentrated sulfuric acid
B react the naphthalene with 2·0 mol of concentrated sulfuric acid
C react the naphthalene with 0·05 mol of concentrated sulfuric acid
D react the naphthalene with 0·1 mol of concentrated sulfuric acid in the presence of a catalyst

L5 Effect of volume or pressure changes

L5-1 50 A

A closed vessel contains nitrogen and hydrogen in equilibrium with NH_3, as shown by the equation below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2\,NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

Which one of the following procedures will shift the equilibrium position to the right?

A decreasing the volume of the system
B increasing the temperature of the system
C introduction of an inert gas into the system
D addition of a catalyst to the system

L5-2 70 A

In which one of the following reactions will the equilibrium position be **unaffected** by a change in volume?

A $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$ $\quad \Delta H = +180 \text{ kJ mol}^{-1}$
B $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\quad \Delta H = -92 \text{ kJ mol}^{-1}$
C $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$ $\quad \Delta H = +380 \text{ kJ mol}^{-1}$
D $C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)$ $\quad \Delta H = +138 \text{ kJ mol}^{-1}$

L5-3 40 A

X_2 and Y_2 form X_2Y_2 according to the equation

$$X_2(g) + Y_2(g) \rightleftharpoons X_2Y_2(g)$$

The volume of an equilibrium mixture of $X_2(g)$, $Y_2(g)$ and $X_2Y_2(g)$ is halved at constant temperature. When the system returns to equilibrium,

A the mass of X_2Y_2 will be greater than at the first equilibrium.
B the mass of X_2Y_2 will be less than at the first equilibrium.
C the mass of X_2Y_2 will be the same as at the first equilibrium.
D there is insufficient information to decide between A, B, and C.

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L5-4 30 B | When 1 dm^3 of 0.1 M ethanoic (acetic) acid is diluted to 10 dm^3 with distilled water

A the concentration of ethanoic acid molecules increases.

B the number of H_3O^+ ions increases.

C the numerical value of the pH of the solution decreases.

D the concentration of ethanoate ion increases.

The next two items refer to the following information

An important reaction which occurs in the atmosphere during thunderstorms can be studied in the laboratory by mixing NO and O_2 gas. The gases react according to the equation

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

L5-5 20 A | When 4 mol of NO and 5 mol of O_2 were mixed and allowed to come to equilibrium in a volume of 1 dm^3, 2 mol of NO_2 was produced.

At this temperature the magnitude of the equilibrium constant, K_c, is equal to

A $\frac{1}{4}$. **B** $\frac{1}{2}$. **C** $\frac{1}{10}$. **D** $\frac{1}{12}$. **E** $\frac{1}{20}$.

L5-6 20 B | If the volume is then decreased, what will be the effect on the mass and the concentration of NO?

A The mass and concentration of NO will increase.

B The mass of NO will decrease, but its concentration will increase.

C The mass and concentration of NO will decrease.

D The mass of NO will remain unchanged, but its concentration will increase.

L6 Effect of temperature changes

L6-1 60 C | The equilibrium constant for a reaction changes as the

A overall pressure increases.

B concentrations of the reagents increase.

C temperature increases.

D reaction proceeds.

L6-2 60 D | Ethene may be produced from ethane by heating in the presence of a catalyst, according to

$$C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g) \quad \Delta H = +138 \text{ kJ mol}^{-1}$$

At 425 °C, and in the presence of 'Speedicrak' patent catalyst, equilibrium is rapidly achieved.

The proportion of ethane converted to ethene at equilibrium would be increased by

A raising the initial pressure of ethane.

B replacing 'Speedicrak' with a more effective catalyst.

C lowering the temperature.

D raising the temperature.

E adding H_2 to the reaction mixture.

L6-3 40 C | Methanol is prepared commercially by reacting CO with H_2 at 400 °C in the presence of a catalyst.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}$$

If a mixture of CO, H_2 and CH_3OH were in equilibrium in a sealed container and the temperature of the gases were raised, the

A total pressure of the gas would decrease.

B rates of the forward and back reactions would remain constant.

C total number of gas molecules would increase.

D value of K would increase.

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L6-4 50 A

The energy of the products in the reaction

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$$

is greater than the total energy of the reactants.

If the temperature of an equilibrium mixture of N_2, O_2 and NO were increased, the mass of NO would

A increase and K would increase.

B increase and K would decrease.

C decrease and K would increase.

D decrease and K would decrease.

The next two items refer to the following information

Carbon monoxide and chlorine react according to the equation

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

The forward reaction is exothermic.

L6-5 50 A

If a mixture of CO, Cl_2, and $COCl_2$ at equilibrium at 1000 °C is cooled to 500 °C at constant volume, then, when the new equilibrium is attained,

A the concentration of CO will decrease.

B the concentration of $COCl_2$ will decrease.

C the value of K will decrease

D the rate of reaction must remain unchanged.

L6-6 30 B

If the volume of an equilibrium mixture of CO, Cl_2, and $COCl_2$ is halved, by increasing the pressure at constant temperature, then, at the new equilibrium

A the concentration of CO will have decreased.

B the concentration of $COCl_2$ will have increased.

C the value of K will increase.

D the rate of reaction must remain unchanged.

L6-7 70 C

One source of the nitrogen required for plant growth involves reaction of nitrogen and oxygen, as represented by the equation

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \quad \Delta H = +180 \text{ kJ mol}^{-1}$$

Raising the temperature of an equilibrium mixture of N_2, O_2 and NO from 500 °C would, if there were no change in the volume occupied by the gases,

A have no effect on the [NO] at equilibrium.

B reduce the [NO] at equilibrium.

C increase the [NO] at equilibrium.

D change the [NO] at equilibrium in an unpredictable direction.

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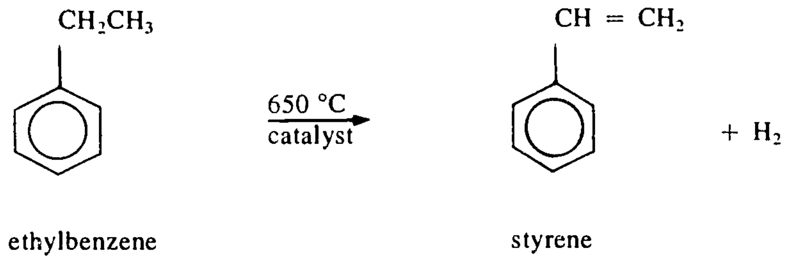
L6-8 30 A

Styrene, which is used extensively as a plastics intermediate, is produced by the dehydrogenation of ethylbenzene.



The reaction is endothermic and is performed in the gaseous state. The conditions which should give a maximum equilibrium yield are

A elevated temperature, reduced pressure.
B elevated temperature, elevated pressure.
C reduced temperature, reduced pressure.
D reduced temperature, elevated pressure.
E elevated temperature; pressure has no effect.
F reduced temperature; pressure has no effect.

The next three items refer to the following information

At room temperature, nitrogen dioxide, NO_2, exists in an equilibrium with dinitrogen tetroxide, N_2O_4. NO_2 is brown, N_2O_4 is colourless.

An estimate of the relative amounts of NO_2 and N_2O_4 present in two samples can be obtained by comparison of the intensities of the brown colour in each sample. In a particular experiment, equal samples of the above equilibrium mixture were placed into two glass capsules, fitted with taps, at room temperature and atmospheric pressure.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H = -58\cdot 2 \text{ kJ mol}^{-1}$$

L6-9 60 B

When one of the capsules is immersed in cold water, the intensity of the brown colour in this sample

A increases.
B decreases.
C remains the same.
D cannot be predicted.

L6-10 40 B

The tap of this cooled capsule is opened to the air for a fraction of a second, allowing a small amount of air to enter.

The intensity of the brown colour in this capsule, relative to the other sample which is still at room temperature is now

A greater than in the second capsule.
B less than in the second capsule.
C the same as in the second capsule.
D unable to be predicted.

L6-11 50 C

The cooled mixture is now returned to room temperature without opening the tap again.

The intensity of the brown colour in this capsule compared to the unaltered sample is

A much greater.
B much less.
C approximately the same.
D unable to be predicted.

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L6-12 50 B

Pure water dissociates to a small extent according to the equilibrium

$$2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

The reaction between aqueous solutions of HCl and NaOH is strongly exothermic. The pH of pure water is 7.0 at 25 °C. The pH of pure water at blood heat (≈37 °C) would be

A greater than 7.0. **B** less than 7.0. **C** equal to 7.0.

The next three items refer to the following information

Some hydrogen and iodine were placed in a sealed vessel and heated to 500 °C, where equilibrium was established according to the equation

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

The reaction is endothermic.

The mixture was then quickly cooled so that no further reaction took place, and the equilibrium was undisturbed. Some I_2 was removed and replaced by an equal amount of radioactive iodine, I_2^*. Equilibrium was then re-established at 500 °C.

L6-13 70 D

Upon re-establishment of the equilibrium mixture, the species present would be

A H_2; I_2^*; HI^*.
B H_2; HI; I_2^*; HI^*.
C H_2; I_2; HI; HI^*.
D H_2; I_2; HI; I_2^*; HI^*.

L6-14 70 E

The volume of the container housing the equilibrium mixture was then halved, while keeping the temperature constant.

It would follow that

A the mass of I_2^* would increase.
B the mass of I_2^* would decrease.
C the mass of HI would decrease.
D the mass of I_2 would increase.
E there would be no change in the relative masses of the reactants and product.

L6-15 60 C

The volume of the container was then returned to its original value and the temperature was increased to 600 °C.

It would follow that, compared to the original equilibrium situation,

A $[HI^*]$ and $[I_2^*]$ would both increase.
B $[HI^*]$ and $[I_2^*]$ would both decrease.
C $[HI^*]$ would increase but $[I_2^*]$ would decrease.
D $[HI^*]$ would decrease but $[I_2^*]$ would increase.
E the reagents would remain unchanged.

L6-16 40 D

A system containing the gases X, Y and Z is used to determine the equilibrium constants for the endothermic reaction $X + Y \rightleftharpoons Z$. Some of the results obtained are shown.

Temperature	K_c
T_1	3×10^{-4}
T_2	6×10^{-5}

The lower temperature and the temperature at which the smaller amount of Z was present were, respectively,

A T_1 and T_1.
B T_1 and T_2.
C T_2 and T_1.
D T_2 and T_2.

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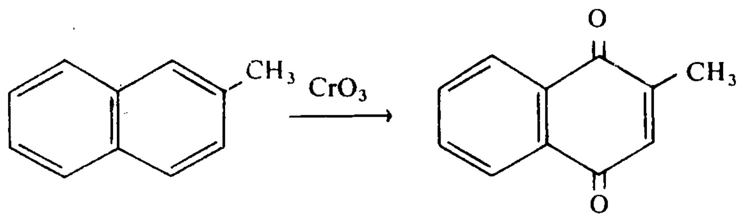
L6-17 Menadione, a chemical which aids blood clotting, can be prepared by the oxidation of 2-methylnaphthalene using chromium trioxide. The reaction is exothermic and ethanoic acid is often used as a catalyst.
50
C

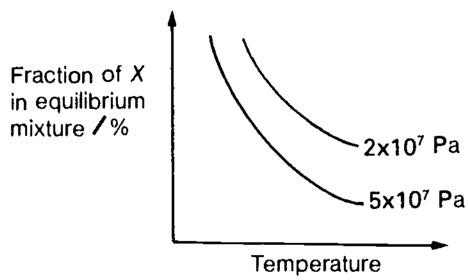


2-methylnaphthalene menadione

In a particular synthesis, 1·4 g (0·01 mol) of 2-methylnaphthalene yielded 0·17 g (0·001 mol) of menadione. If the reaction was rapid, which of the following could explain the poor yield?

A use of excess chromium trioxide
B use of a catalyst other than ethanoic acid
C heating the reaction mixture
D precipitation of menadione as it forms

L6-18 The graph below shows how the fraction of a substance, *X*, produced in an equilibrium mixture varies with temperature at pressures of 2×10^7 Pa and 5×10^7 Pa.
40
C



In which of the following equilibria could *X* represent the underlined species?

A $N_2(g) + 3H_2(g) \rightleftharpoons 2\underline{NH_3}(g)$ $\Delta H = -92$ kJ mol^{-1}
B $SO_3(g) \rightleftharpoons \underline{SO_2}(g) + \frac{1}{2}O_2(g)$ $\Delta H = +380$ kJ mol^{-1}
C $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6\underline{H_2O}(g)$ $\Delta H = -1267$ kJ mol^{-1}
D $N_2(g) + O_2(g) \rightleftharpoons 2\underline{NO}(g)$ $\Delta H = +181$ kJ mol^{-1}

L7 Effect of catalysts

L7-1 A catalyst is a substance which, when present during a chemical reaction, changes the
90
B

A amount of products obtained at equilibrium.
B rate of attaining equilibrium.
C concentration of the products at equilibrium.
D equilibrium constant at a given temperature.

L7-2 If a catalyst is added to a reversible reaction at equilibrium, then it alters the rate of
60
C

A the forward reaction only.
B the back reaction only.
C both the forward and back reactions equally.
D the forward reaction more than the rate of the back reaction.

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L7-3 60 B | A synthetic pineapple essence, ethyl butanoate, is manufactured from butanoic acid and ethanol.

$$C_3H_7COOH(l) + C_2H_5OH(l) \rightleftharpoons C_3H_7COOC_2H_5(l) + H_2O(l)$$

If a mixture of butanoic acid, ethanol, ethyl butanoate and water were at equilibrium at 50 °C, adding a catalyst to the system would increase the

A value of K for the reaction at 50 °C.
B rate of the reverse reaction.
C concentration of ethyl butanoate.
D rate of the forward reaction to a greater extent than the reverse reaction.

The next three items refer to the following information

A mixture of gases is in equilibrium at 500 °C as represented by the equation

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}$$

The magnitude of the equilibrium constant, K_c, at this temperature is 1.1×10^{-7}.

The following changes are made, independently but successively, on the system. For each, choose the alternative which best describes the effect of that change on the system. (Assume that the system is at equilibrium before each change is made.)

L7-4 40 C | The temperature is increased to 650 °C at constant volume.

A The mass of NH_3 increases.
B The equilibrium constant increases.
C The number of molecules of H_2 increases.
D No effect on the equilibrium position is observed.

L7-5 30 D | More catalyst is added to the system (at 650 °C and constant volume).

A The mass of NH_3 increases.
B The number of molecules of H_2 increases.
C The equilibrium constant increases.
D No effect on the equilibrium position is observed.

L7-6 20* A | The volume is halved (at 650 °C).

A All concentrations are increased.
B The concentration of ammonia only is increased.
C The equilibrium constant is increased.
D No effect on the equilibrium position is observed.

L8 Manipulation of equilibrium constants

L8-1 60 C | Methanal is manufactured by the oxidation of methanol

$$CH_3OH(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons CH_2O(g) + H_2O(g)$$

If the equilibrium constant for this reaction were K_1, the equilibrium constant for the reaction

$$2H_2O(g) + 2CH_2O(g) \rightleftharpoons O_2(g) + 2CH_3OH(g)$$

at the same temperature would be

A $-2K_1$. **B** $\frac{2}{K_1}$. **C** $\frac{1}{K_1^2}$. **D** $\frac{1}{2K_1^2}$. **E** $-K_1^2$.

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L8-2 50 A

The equilibrium constants for the reactions

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

and $CO(g) + \frac{1}{2}O_2(g) \rightleftharpoons CO_2(g)$

are K_1 and K_2 respectively. The equilibrium constant for the reaction

$$H_2O(g) \rightleftharpoons H_2(g) + \frac{1}{2}O_2(g)$$

at the same temperature is

A $\frac{K_1}{K_2}$. **B** $K_1 \times K_2$. **C** $K_1 - K_2$. **D** $\frac{K_2}{K_1^2}$

L9 Heterogeneous equilibria

L9-1 30 C

Ag^+ ions react with Fe^{2+} ions according to the equation

$$Ag^+(aq) + Fe^{2+}(aq) \rightleftharpoons Ag(s) + Fe^{3+}(aq)$$

The concentration of Ag^+ at equilibrium is **not** changed by adding

A $Fe^{2+}(aq)$. **B** $Cl^-(aq)$. **C** $Ag(s)$. **D** $Fe^{3+}(aq)$.

The next two items refer to the following information

A solution containing Sn^{2+} and Zn^{2+} ions is in equilibrium with zinc and tin.

$$Zn(s) + Sn^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Sn(s)$$

The equilibrium constant for the reaction, K, is equal to $\frac{[Zn^{2+}]}{[Sn^{2+}]}$.

L9-2 70 B

The concentrations of zinc and tin are not included in the expression for K because

A the concentrations of the two species cancel.
B the amount of solid present does not affect the equilibrium.
C temperature affects the concentration of a solid.
D temperature does not affect the concentration of a solid.

L9-3 80 C

If the solution were diluted

A more Sn^{2+} ions would be formed.
B the mass of tin would increase.
C the concentration of both Sn^{2+} and Zn^{2+} would decrease.
D the mass of both tin and zinc would decrease.

L9-4 50 D

For the reaction

$$Fe^{2+}(aq) + Ag^+(aq) \rightleftharpoons Fe^{3+}(aq) + Ag(s) \quad \Delta H = -65.7 \text{ kJ mol}^{-1}$$

Which of the following **increases** the value of K?

A removing solid silver from the system
B removing water from the system
C adding silver nitrate crystals
D decreasing the temperature

L9-5 30 A, C

In which one or more of the following chemical equilibrium systems will the position of equilibrium be shifted to the right by an increase in volume?

A $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
B $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$
C $C_3H_8(g) + 5O_2(g) \rightleftharpoons 3CO_2(g) + 4H_2O(g)$
D $Cl_2(g) + 3F_2(g) \rightleftharpoons 2ClF_3(g)$

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L9-6 The magnitude of the equilibrium constant, K_c, for the reaction
40
C

$$H_2O(l) \rightleftharpoons H_2O(g)$$

is 1.3×10^{-3} at 25 °C.

A sealed flask containing water at 25 °C has a water vapour concentration of 6.0×10^{-5} M. Which of the following will occur?

A The mass of liquid present will increase.

B The mass of liquid present will remain unchanged.

C The rate of the forward reaction will be greater than the rate of the back reaction.

D The forward and back reactions will proceed at the same rate.

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M REACTION RATES

M1 Factors affecting rate

M1-1 80 D

Increasing the temperature at which reactions are performed

A increases the value of K of all reactions.
B decreases the value of K of all reactions.
C has no effect on the value of K of all reactions.
D increases the rate of most reactions.

M1-2 80 A

A flour mill is especially prone to explosions unless suitable precautions are taken. The **best** explanation for this is that the fine particles of flour

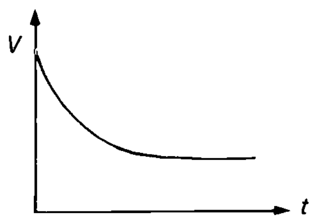
A have a very large surface area causing combustion reactions to proceed much faster.
B have a high translational vibration which is easily converted to heat energy.
C have a higher kinetic energy than the activation energy required for reaction.
D can produce a fast chain reaction by collision of one particle with another.

M1-3 80 C

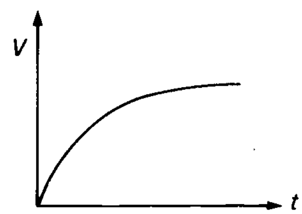
Several marble chips were added to a test tube containing hydrochloric acid solution, producing carbon dioxide gas.

The volume of carbon dioxide gas (V) evolved after known times (t) was measured during the reaction. Which one of the following graphs would be obtained from the results of this experiment?

A

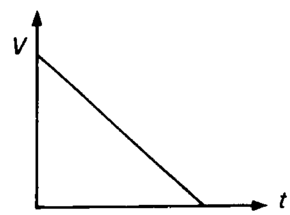


C



B

D



M1-4 60 B

Which of the following procedures is **most** likely to increase the rate of the reaction between 2 M sodium thiosulfate solution and 1 M hydrochloric acid at 25 °C and 1.0×10^5 Pa pressure?

A lower the temperature of the reaction mixture
B increase the concentration of the reactants
C increase the pressure on the reaction mixture
D increase the amount of hydrochloric acid solution

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M1-5 90 **B**

Which one of the following sets of conditions is most likely to cause a given reaction in aqueous solution to occur most rapidly?

A high concentration of reactants, low temperature

B high concentration of reactants, high temperature

C low concentration of reactants, low temperature

D low concentration of reactants, high temperature

M1-6 70 **C**

Which one of the following would **not** change the initial rate of reaction between zinc and 1 M nitric acid?

A the addition of a catalyst

B a change in the temperature of the reactants

C use double the volume of nitric acid solution

D breaking down the zinc into smaller particles

M1-7 70 **A**

Which one of the following procedures is *not* likely to increase the rate of reaction of a gaseous system?

A increasing the volume of the system at constant temperature

B increasing the temperature of the system at constant volume

C increasing the concentration of the reactants at constant temperature

D increasing the pressure of the system at constant temperature

M1-8 50 **C**

Which one of the following procedures would be expected to **decrease** the rate of the reaction

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g) \qquad \Delta H = -242 \text{ kJ mol}^{-1}?$$

A increase the temperature

B decrease the volume at constant temperature

C decrease the pressure at constant temperature

D add a catalyst

M1-9 70 **D**

Calcium metal will readily displace hydrogen gas from cold water and from dilute hydrochloric acid. When a piece of calcium is added to dilute sulfuric acid, bubbles of gas appear, and then the reaction appears to cease. The most likely explanation for these observations is that

A hydrochloric acid is a stronger acid than sulfuric acid.

B calcium reacts with dilute sulfuric acid, but the evolved hydrogen immediately reacts with the water to form H_3O^+ ions.

C the calcium is covered by a layer of oxide which is soluble in dilute hydrochloric acid and water, but not in dilute sulfuric acid.

D after an initial reaction with the dilute sulfuric acid, the calcium becomes coated with an insoluble layer of calcium sulfate.

M2 Units of rate

M2-1 80 **B**

The rate of a chemical reaction is usually expressed in the units

A s^{-1}.

B mol dm^{-3} s^{-1}.

C mol s^{-1}.

D mol^n dm^{-n} s^{-n}, where n is the order of the reaction.

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M3 Stoichiometry and reaction rates

M3-1 | 60 | D

Hydrogen peroxide reacts with iodide ion according to the equation

$$H_2O_2(l) + 2H^+(aq) + 3I^-(aq) \rightarrow I_3^-(aq) + 2H_2O(l)$$

If the rate at which I^- is consumed is 3.0×10^{-4} mol dm^{-3}s^{-1}, then the rate at which

A H_2O_2 is consumed is 9.0×10^{-4} mol dm^{-3}s^{-1}.
B H^+ is consumed is 3.0×10^{-4} mol dm^{-3}s^{-1}.
C I_3^- is formeed is 9.0×10^{-4} mol dm^{-3}s^{-1}.
D H_2O is formed is 2.0×10^{-4} mol dm^{-3}s^{-1}.

M3-2 | 60 | D

Consider the following reaction:

$$X(aq) + 2Y(aq) \rightleftharpoons Z(aq)$$

If all concentrations were expressed in mol dm^{-3}, it can be inferred that

A doubling the absolute temperature of the reaction mixture doubles the reaction rate.
B doubling the concentration of Y doubles the molar rate of formation of Z.
C the molar rate of consumption of X is the same as the molar rate of consumption of Y.
D the molar rate of consumption of Y is double the molar rate of formation of Z.

M4 Activation energy

M4-1 | 80 | A

A burning match is usually used to start the combustion of natural gas in air because

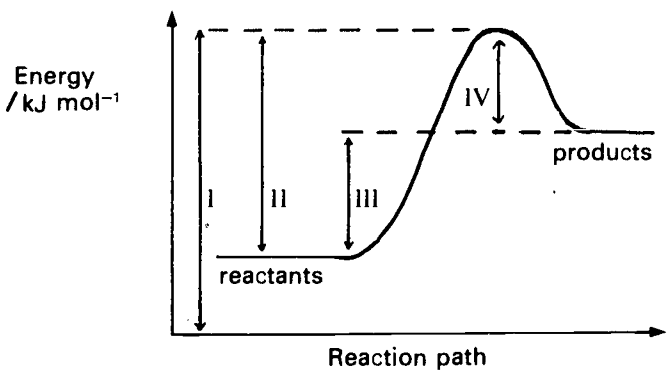
A an energy barrier must be overcome before the reaction can proceed.
B ΔH for the reaction is larger than the energy available at room temperature.
C the reaction is endothermic and must be driven by an external energy source.
D the equilibrium constant for the reaction increases as temperature increases.

The next two items refer to the following information

The energy changes which occur during the reaction

$$H_2O(s) \rightarrow H_2O(l)$$

are represented below.



M4-2 | 70 | B

The activation energy for the reaction is equal to the energy change

A I. **B** II. **C** III. **D** IV.

M4-3 | 90 | C

The change in enthalpy for the reaction, ΔH, is equal to the energy change

A I. **B** II. **C** III. **D** IV.

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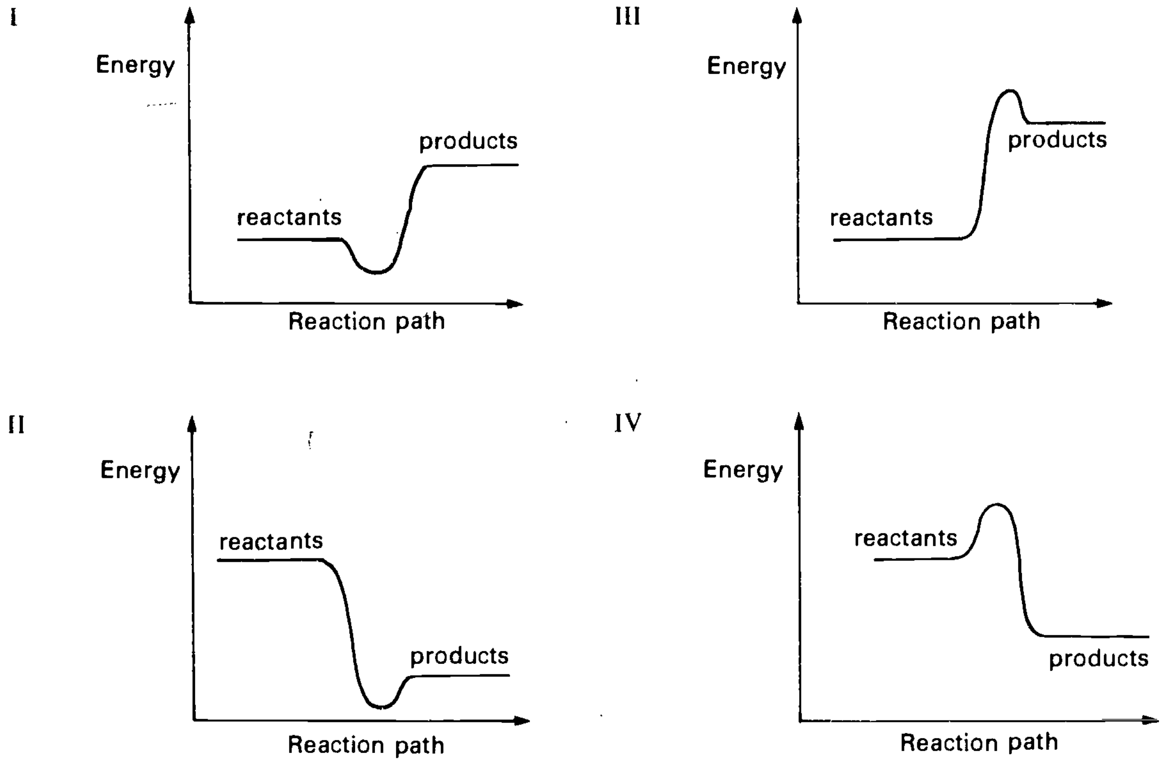
The next three items refer to the following information

The graphs below represent changes in potential energy during the course of a chemical reaction.



M4-4 60 **D**

Which graph could correspond to the reaction

$NO_2(g) \rightarrow \frac{1}{2}N_2(g) + O_2(g) \qquad \Delta H = -33.7 \text{ kJ mol}^{-1}$?

A I **B** II **C** III **D** IV

M4-5 50 **C**

Which graph could correspond to the melting of ice?

A I **B** II **C** III **D** IV

M4-6 40 **D**

Which graph could correspond to the reaction

$CH_4(g) + O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$?

A I **B** II **C** III **D** IV

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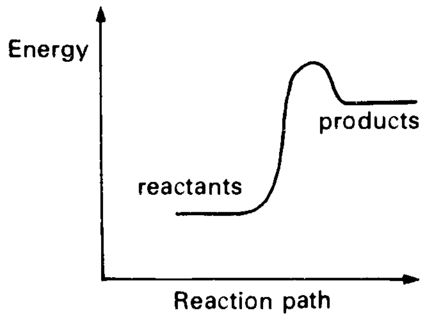
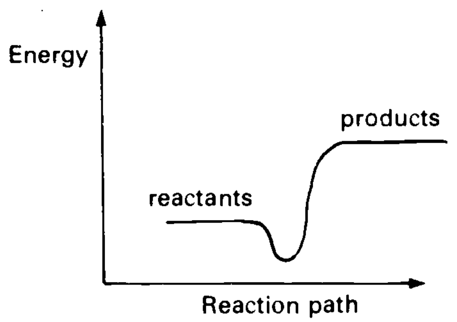
M4-7 70 A | Which one of the following diagrams **best** represents the change in energy along the reaction pathway for an endothermic reaction?

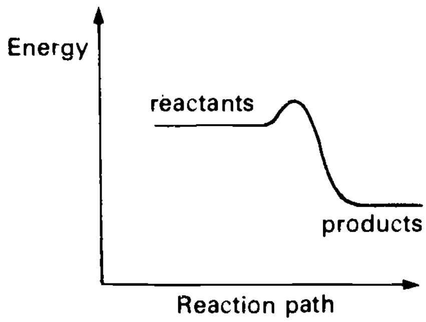
A



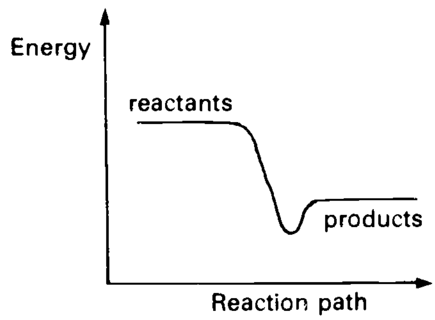
C



B



D



M4-8 60 D | A slight increase in temperature often causes a dramatic increase in the rate of a chemical reaction because the

A average frequency of collisions between particles increases substantially.
B energy of collisions between particles increases substantially.
C equilibrium constant for a reaction is dependent upon temperature.
D number of molecules with energy greater than the activation energy increases substantially.

M5 Catalysis

M5-1 70 C | The activation energy of a reaction is usually

A equal to the ΔH of the reaction.
B equal to the sum of the energies of the reactants and products.
C decreased by the addition of a catalyst.
D decreased by increasing the temperature of the system.

M5-2 80 A | A catalyst in a chemical reaction

A changes the activation energy of the reaction.
B changes the rate of the forward reaction only.
C decreases the rate of the back reaction.
D increases the equilibrium constant for the reaction.

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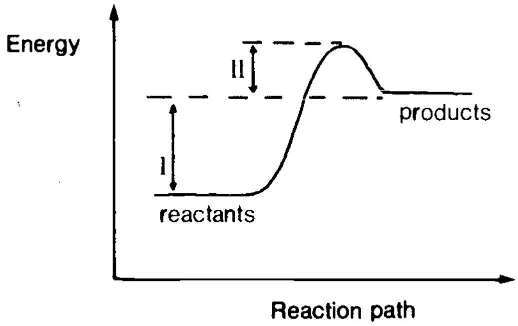
M5-3 70 B | The change in energy during a chemical reaction is shown below. Energy changes I and II are also shown.

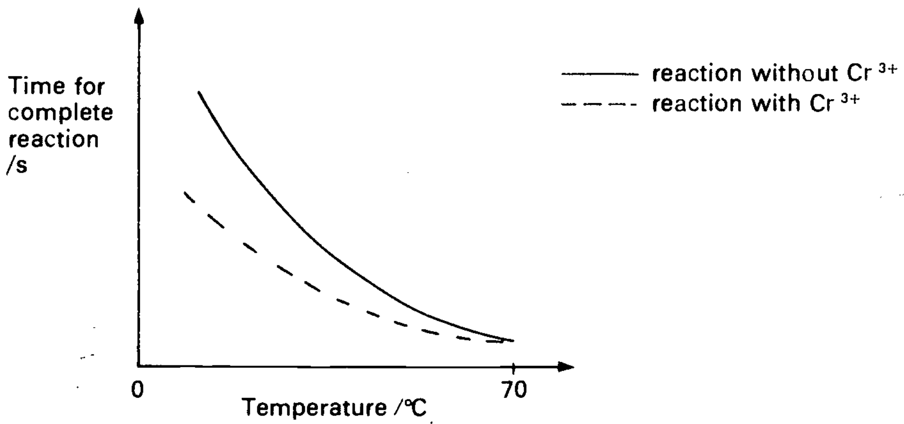


The effect of adding a catalyst to the system is to

A increase the size of II only.
B decrease the size of II only.
C increase the size of I and decrease the size of II.
D decrease the size of I and increase the size of II.
E decrease the size of both I and II.

The next three items refer to the following information

In an experimental investigation of the rate of reaction between magnesium and dilute nitric acid, the time taken for the complete reaction of a given amount of magnesium ribbon was recorded at various temperatures. A second set of observations was made using the same amount of magnesium, but with the addition of one drop of solution containing chromium(III) ions. The results were expressed graphically as follows:



M5-4 50* A | The time taken for the disappearance of the magnesium is only an approximate indication of reaction rate because

A the reaction rate is not a constant. It decreases as the reaction proceeds.
B the magnesium reacts quickly with the acid.
C the reaction rate is not a constant. It increases as the magnesium reacts.
D it may be difficult to measure exactly equal amounts of magnesium ribbon.

M5-5 70 D | The best explanation of the relative positions of the two curves at about 20 °C is that

A the chromium(III) ion reacts with impurities on the surface of the magnesium.
B the reaction of chromium(III) ion with nitric acid is exothermic and increases the temperature.
C the chromium(III) ion makes it more difficult for the magnesium to react.
D the chromium(III) ion is acting as a catalyst.

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M5-6 Above 70 °C the two curves coincide. The best explanation of this observation is that

50

B

A the activation energy for the reaction between magnesium and nitric acid decreases as the temperature rises.

B most reactant particles then have more than the energy required for direct reaction.

C nitric acid forms a thick impenetrable oxide layer on magnesium above 70 °C.

D the ΔH for the reaction is greater than the activation energy for the reaction above 70 °C.

M5-7 Addition of a catalyst to a chemical reaction

70

D

A increases the value of the equilibrium constant for the reaction.

B reduces the energy of both the reactants and products.

C increases the rate of the forward reaction more than that of the back reaction.

D allows the reaction to proceed by an alternative pathway.

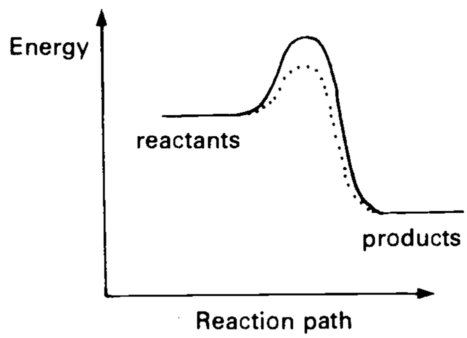
M5-8 At 450 °C the rate of reaction between sulfur dioxide and oxygen gas is slow, but increases substantially if vanadium(V) oxide catalyst is added.

70

A

Which one of the following graphs best shows the energy changes occurring during the catalysed and uncatalysed reaction? (The catalysed reaction is represented by a dotted line (.....) and the uncatalysed reaction by an unbroken line (_____).

A



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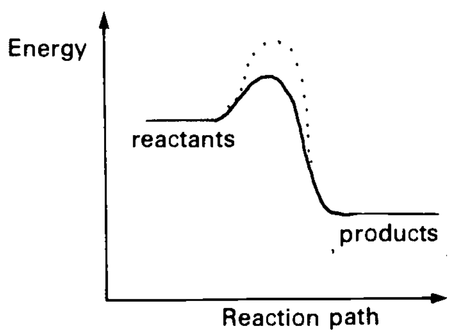

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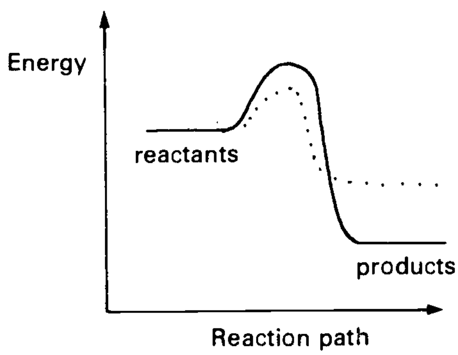

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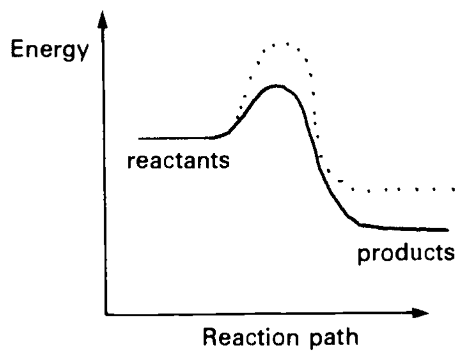

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The next three items refer to the following information

X is undergoing decomposition in a closed vessel according to the equation

$$X(g) \rightleftharpoons Y(g) + Z(g)$$

The table below gives the non-equilibrium concentrations L, M, N of X at successive time intervals t_0, t_1 and t_2 under several conditions of temperature and catalyst.

Temperature	Time		
	t_0	t_1	t_2
300 K	L_0	M_1	N_1
400 K	L_0	M_2	N_2
300 K with catalyst	L_0	M_3	N_3

M5-9 30 **A**

Concerning concentrations M_1 and M_2, and assuming that what is true for most reactions is true for X,

A M_1 would be numerically greater than M_2.

B M_2 would be numerically greater than M_1.

C M_1 would be nearly the same as M_2.

D it is impossible to determine from the data which would be the greater, M_1 or M_2.

M5-10 40 **C**

Concerning concentrations N_1, N_2 and N_3, it is reasonable to conclude that

A N_2 would be numerically greater than N_1.

B N_3 would be numerically greater than N_1.

C N_3 would be numerically less than N_1.

D N_3 would be numerically greater than N_2, which would in turn be greater than N_1.

M5-11 50* **D**

If at a temperature of 400 K and in the absence of a catalyst, the decomposition of X were allowed to proceed to equilibrium, the concentration of X would be

A numerically greater than the equilibrium concentration at 300 K.

B numerically less than the equilibrium concentration at 300 K.

C **A** or **B** above, depending on both the sign and magnitude of ΔH for the reaction.

D **A** or **B** above, depending on whether the reaction is endothermic or exothermic.

M6 Reaction mechanisms

M6a Rate laws, Order, Molecularity

M6a-1 80 **C**

For a second order reaction, increasing the concentration of all reactants by a factor of 3 will increase the rate of reaction by a factor of

A 3. **B** 6. **C** 9. **D** 27.

M6a-2 80 **E**

The order of the reaction $A + 2B \rightarrow C + D$ is

A 1.

B 2.

C 3.

D 5.

E determined only by experiment.

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The next two items refer to the following information

The rate of the reaction $H_2 + NO \rightarrow H_2O + \frac{1}{2} N_2$ at 800 °C is given by the expression $Rate = 8{\cdot}8 \times 10^4 [H_2][NO]^2$.

M6a-3 The order of the reaction is
70
B

A 2. B 3. C 7. D $8{\cdot}8 \times 10^4$.

M6a-4 If the concentration of NO were doubled, the rate of the reaction would increase by a factor of
90
D

A $\frac{1}{4}$. B $\frac{1}{2}$. C 2. D 4.

M6a-5 The molecularity of a reaction is the
50
A

A number of particles involved in the slow step of a reaction.
B number of molecules participating in the reaction mechanism.
C change in the number of molecules during a chemical reaction.
D number of different species in the rate law.
E number of molecules produced in the rate determining step.

The next two items refer to the following information

It has been suggested that the reaction between nitrogen oxide and hydrogen to form nitrogen and water might occur by the mechanism

$$2NO + H_2 \xrightarrow{slow} N_2 + H_2O_2$$

$$H_2O_2 + H_2 \xrightarrow{fast} 2H_2O$$

M6a-6 The order of the reaction predicted by this mechanism is
30
C

A 1. B 2. C 3. D 4.

M6a-7 The molecularity of the slow step of the reaction is likely to be
30
B

A 2. B 3. C 4. D 5. E 9.

The next three items refer to the following information

The equation for the reaction between hydrogen peroxide and hydrogen iodide in acidic solution is

$$H_2O_2 + 2H^+ + 2I^- \rightarrow 2H_2O + I_2.$$

The rate equation for the reaction is

$$Rate\ of\ formation\ of\ I_2 = k[H_2O_2][H^+][I^-]$$

M6a-8 Equal volumes of 0·100 M solutions of the reactants were rapidly mixed.
10* The initial rate of reaction in mol $dm^{-3} s^{-1}$ was
D

A $(0{\cdot}100)k$.
B $(0{\cdot}100)^2k$.
C $(0{\cdot}100)^2k^2$.
D $(0{\cdot}050)^2k$.

M6a-9 If the number of moles of I_2 formed per second were x, the number of moles of HI consumed per second
80 would be
C

A $\frac{x}{2}$. B x. C $2x$. D $4x$.

M6a-10 The order of reaction with respect to hydrogen peroxide is
60
B

A 0. B 1. C 2. D k.

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M6a-11 If the reaction $2X \rightarrow 2Z + Y$ is a first order process, then
50
D

A the reaction must be written $X \rightarrow Z + \frac{Y}{2}$.

B the rate of formation of products decreases by a factor of 8 if [X] is reduced by a factor of 4.

C the rate of formation of products decreases by a factor of 16 if [X] is reduced by a factor of 4.

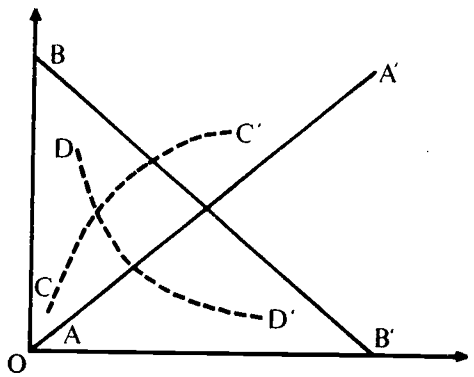
D the rate of disappearance of X will double if [X] is doubled.

E the rate of disappearance of X will quadruple if [X] is doubled.

M6a-12 The graph below shows the variation of the initial rate of decomposition of H_2O_2 with initial concentration of various samples of H_2O_2 solution.
30
A

Which line indicates first order kinetics for the decomposition of hydrogen peroxide?

Rate of decomposition of H_2O_2 /mol dm^{-3} s^{-1}



$[H_2O_2]$ /mol dm^{-3}

A AA′ **B** BB′ **C** CC′ **D** DD′

M6a-13 The rate of formation of I_2 from the reaction
90
D

$$2NO_2^- + 2I^- + 4H^+ \rightarrow I_2 + 2NO + 2H_2O$$

is doubled when $[NO_2^-]$ is doubled, halved when $[I^-]$ is halved and increased by a factor of four when $[H^+]$ is doubled.

The rate law for this reaction is

A *Rate* α $[NO_2^-]^2 [I^-]^2 [H^+]^4$.

B *Rate* α $[NO_2^-] [I^-]^1 [H^+]^4$.

C *Rate* α $[H^+]^2$.

D *Rate* α $[NO_2^-] [I^-] [H^+]^2$.

M6a-14 The following data were obtained for the reaction
70
D

$$C_6H_5CHO + HCN \rightarrow C_6H_5CH(OH)CN$$

at 25 °C.

Experiment	Initial Concentration of C_6H_5CHO /mol dm^{-3}	Initial Concentration of HCN /mol dm^{-3}	Initial Rate of Formation of $C_6H_5CH(OH)CN$ /millimol dm^{-3} s^{-1}
I	0·20	0·20	0·06
II	0·20	0·40	0·24
III	0·40	0·40	0·24

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The rate of the reaction is proportional to

A $[C_6H_5CHO]$.
B $[HCN]$.
C $[C_6H_5CHO][HCN]$.
D $[HCN]^2$.

M6a-15
40
C

The reaction $3X + 2Y \rightarrow Z$ is believed to proceed by a mechanism involving a highly reactive compound, C.

Which of the following could be a mechanism for this reaction?

A $X + Y \rightarrow C + Z$
$\quad + X \rightarrow Z$

B $X \rightarrow 2C$
$C + Y \rightarrow Z$

C $X + Y \rightarrow C$
$2C + X \rightarrow Z$

D $X + Y \rightarrow 2C$
$2C + 2X \rightarrow Z$

M6a-16
80
A

The reaction

$$H_2O_2 + 2H_3O^+ + 2I^- \rightarrow 4H_2O + I_2$$

is believed to occur in the following stages:

$$H_2O_2 + I^- \xrightarrow{slow} H_2O + IO^-$$
$$IO^- + H_3O^+ \xrightarrow{fast} HIO + H_2O$$
$$HIO + H_3O^+ + I^- \xrightarrow{fast} 2H_2O + I_2$$

If this mechanism were correct, the rate of formation of iodine would be proportional to

A $[H_2O_2][I^-]$.
B $[H_2O_2][I^-]^2$.
C $[H_2O_2][H_3O^+]^2[I^-]^2$.
D $[IO^-][H_3O^+]^2[HIO][I^-]$.

M6a-17
70
A

It has been postulated that the following mechanism occurs in the reaction between HBr and O_2.

I $HBr + O_2 \rightarrow HOOBr$
II $HOOBr + HBr \rightarrow 2HOBr$
III $HOBr + HBr \rightarrow H_2O + Br_2$

The reaction is found experimentally to be first order with respect to both HBr and O_2. The rate of the reaction is probably determined by

A step I.
B step II.
C step III.
D two of the above.

The next two items refer to the following information

The rate of substitution of Br for OH in 2-methylpropan-2-ol, according to the equation

$$(CH_3)_3COH + H^+ + Br^- \rightarrow (CH_3)_3CBr + H_2O$$

follows the rate law

$$\frac{d[(CH_3)_3CBr]}{dt} = k[H^+][(CH_3)_3COH],$$

where $\frac{d[(CH_3)_3CBr]}{dt}$ signifies the rate of formation of $(CH_3)_3CBr$.

M6a-18
60
D

The rate of reaction would increase if

A F^- were substituted for Br^-.
B water were added.
C $[Br^-]$ were doubled.
D more HBr gas were bubbled into the mixture.

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M6a-19 A mechanism consistent with the information given above is
50
A

A i $(CH_3)_3\,COH + H^+ \xrightarrow{slow} (CH_3)_3\,C^+ + H_2O$
ii $(CH_3)_3\,C^+ + Br^- \xrightarrow{fast} (CH_3)_3\,CBr.$

B i $(CH_3)_3\,COH + H^+ \xrightarrow{fast} (CH_3)_3\,C^+ + H_2O$
ii $(CH_3)_3\,C^+ + Br^- \xrightarrow{slow} (CH_3)_3\,CBr.$

C $(CH_3)_3\,COH + H^+ + Br^- \xrightarrow{slow} (CH_3)_3\,CBr + H_2O.$

D i $(CH_3)_3\,COH + H^+ \xrightarrow{fast} (CH_3)_3\,COH_2{}^+$
ii $(CH_3)_3\,COH_2{}^+ + Br^- \xrightarrow{slow} (CH_3)_3\,CBr + H_2O.$

E i $(CH_3)_3\,COH + Br^- \xrightarrow{slow} (CH_3)_3\,CBr + OH^-$
ii $OH^- + H^+ \xrightarrow{fast} H_2O.$

M6b Electrophiles, Nucleophiles

M6b-1 In the reaction sequence
70
A

$$HNO_3 + 2H_2SO_4 \rightarrow \underline{NO_2{}^+} + H_3O^+ + 2HSO_4{}^{2-}$$

$$\underline{NO_2{}^+} + C_6H_6 \rightarrow C_6H_5NO_2 + H^+$$

the underlined species would be best described as a (an)

A electrophile. **C** radical.
B nucleophile. **D** carbonium ion.

M6b-2 Which one of the following species *cannot* act as a nucleophile?
80
D

A HF **B** H_2O **C** NH_3 **D** CH_4 **E** Br^-

M6b-3 The order of **decreasing** nucleophilic reactivity of the three species, H_3O^+, H_2O and OH^-, is
80
C

A $H_3O^+ > H_2O > OH^-$. **C** $OH^- > H_2O > H_3O^+$. **E** $H_2O > H_3O^+ > OH^-$.
B $H_2O > OH^- > H_3O^+$. **D** $OH^- > H_3O^+ > H_2O$.

M6b-4 CH_3CH_2I reacts with CH_3CH_2ONa in CH_3CH_2OH to produce $CH_3CH_2OCH_2CH_3$ and NaI.
70 The nucleophile in this reaction is probably
C

A CH_3CH_2I. **C** $CH_3CH_2O^-$. **E** $CH_3CH_2{}^+$.
B I^-. **D** CH_3CH_2OH.

M6c Electrophilic substitution reactions

M6c-1 Bromobenzene is formed when benzene and bromine react in the presence of aluminium bromide. It is
40 believed that in the first step of the reaction Br^+ is generated by the process
D

$$AlBr_3 + Br_2 \rightleftharpoons AlBr_4{}^- + Br^+.$$

The mechanism of the reaction step in which bromobenzene is formed is therefore likely to be

A S_N1. **C** addition. **E** radical substitution.
B S_N2. **D** electrophilic substitution.

M6d Nucleophilic substitution reactions

M6d-1 The attack of CH_3S^- on CH_3Cl is represented by
60
B

$$CH_3S^- \curvearrowright CH_3 \overset{\curvearrowright}{-} Cl$$

This mechanism is best classified as

A S_N1. **B** S_N2. **C** addition. **D** initiation. **E** condensation.

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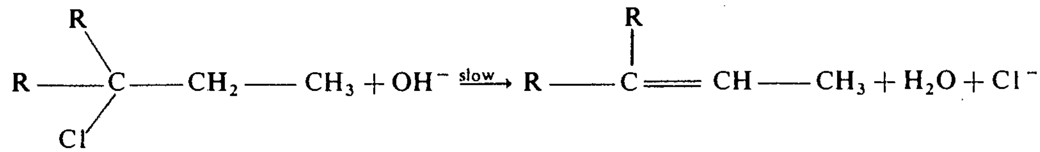
M6d-2 Which of the following mechanisms may be classified as S_N2?
30
C

A



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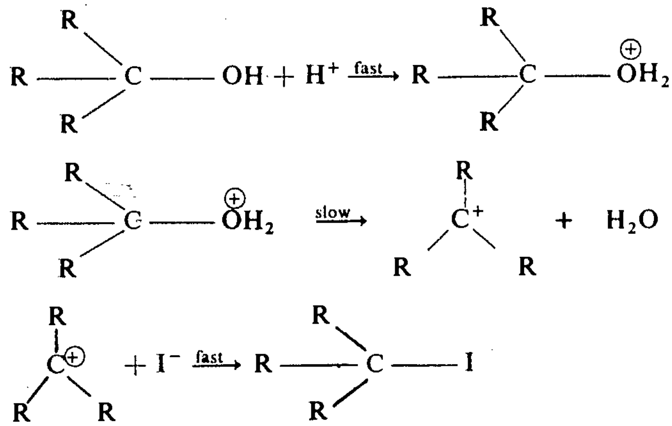

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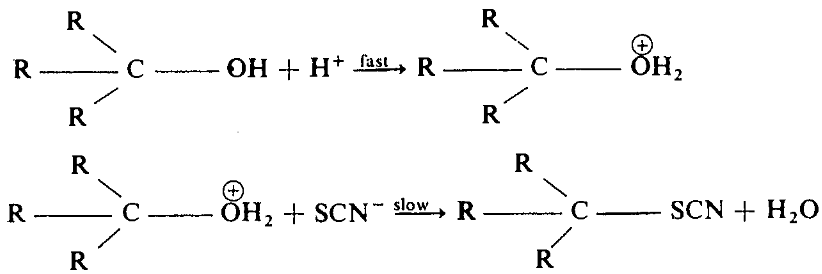

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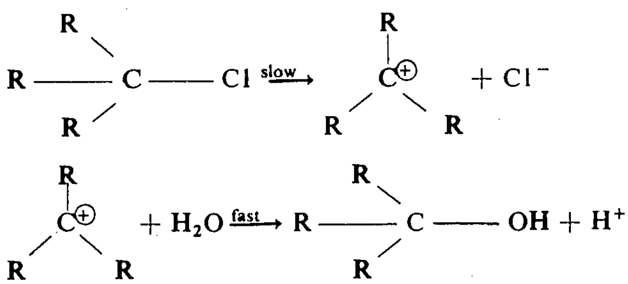

M6d-3 In an experiment, the rate law for the formation of 2-hydroxypropane from 2-bromopropane and sodium hydroxide in a particular solvent was found to be
90
B

$$Rate = 4{\cdot}7 \times 10^{-5}\,[(CH_3)_2CHBr]\,[OH^-] + 0{\cdot}24 \times 10^{-5}\,[(CH_3)_2CHBr].$$

Which of the following statements is most likely to be correct?

A The rate law would be almost identical in other solvents.

B The reaction was proceeding by both unimolecular and bimolecular mechanisms.

C The rate law indicates third order kinetics.

D An electrophilic substitution reaction was occurring in preference to a nucleophilic substitution reaction.

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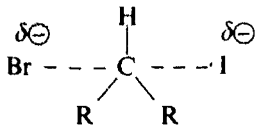
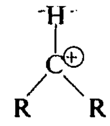
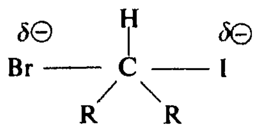
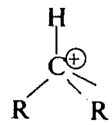
M6d-4
70
C

Which of the following best represents the structure of a species formed in an S_N1 reaction between an alkyl bromide, R_2CHBr, and the I^- ion?

A 

C 

B 

D 

M6d-5
80
B

The reaction between a bromoalkane and hydroxide ion can be represented by the equation

$$RBr + OH^- \rightarrow ROH + Br^-.$$

It is found experimentally that the reaction rate for a particular reaction is proportional to the concentration of RBr, but is independent of the concentration of OH^-. Which of the following statements is **inconsistent** with these observations?

A The reaction shows first order.

B The attack of R^+ by OH^- is the rate determining step.

C The breakage of the R-Br bond is a slow reaction.

D The rate determining step is unimolecular.

E The R-Br bond breaks before the OH^- attacks R.

M6d-6
90
B

Which of the following carbonium ions has the greatest stability?

A $(CH_3)_2CH^+$ **C** $CH_3CH_2^+$

B $(CH_3)_3C^+$ **D** CH_3^+

M6d-7
80
A

In which of the following lists are carbonium ions given in increasing order of stability?

A $CH_3CH_2^+ < (CH_3)_2CH^+ < (CH_3)_3C^+$

B $(CH_3)_2CH^+ < CH_3CH_2^+ < (CH_3)_3C^+$

C $(CH_3)_3C^+ < (CH_3)_2CH^+ < CH_3CH_2^+$

D $(CH_3)_3C^+ < CH_3CH_2^+ < (CH_3)_2CH^+$

M6d-8
80
D

Which of the following is likely to react most rapidly by an S_N2 mechanism?

A CH_3CH_2Br **C** $(CH_3CH_2)_3CBr$

B $CH_3CHBrCH_2CH_3$ **D** CH_3Br

M6d-9
80
C

Which of the following compounds has the greatest steric hindrance to attack by a nucleophile?

A CH_3Br **C** $(CH_3CH_2)_2CHBr$

B $CH_3CH_2CH_2Br$ **D** $(CH_3)_2CHBr$

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M6d-10 70 C

In order to facilitate 2-chloropropane, $CH_3CHClCH_3$, to react with a nucleophile by an S_N2 mechanism, it would be best to

A increase the temperature.
B use a small amount of nucleophile.
C use a strong nucleophile.
D use a very polar solvent.

M6d-11 70 D

Which of the following solvents would be most likely to facilitate the reaction of OH^- with $(CH_3)_2CHBr$ by the S_N1 mechanism (assuming that the reactants are soluble in each case)?

A CH_3OH
B propanone (acetone)
C CCl_4
D H_2O
E $CHCl_3$

M6d-12 50 B

Which of the following lists contains the solvents water, carbon tetrachloride, acetone and ethanol in increasing order of their ability to promote the S_N1 mechanism?

A water, carbon tetrachloride, acetone, ethanol
B ethanol, acetone, carbon tetrachloride, water
C carbon tetrachloride, acetone, water, ethanol
D ethanol, carbon tetrachloride, water, acetone
E carbon tetrachloride, acetone, ethanol, water

M6d-13 50 C

It is desired to react I^- and CH_3Br by the S_N2 mechanism. Which of the following solvents would be most likely to facilitate the desired mechanism (assuming that the reactants are soluble in each case)?

A CH_3OH
B $CHCl_3$
C CCl_4
D H_2O

M6d-14 50 C

Which of the following bromoalkanes would be expected to undergo **most** rapid nucleophilic substitution on hydrolysis with pure water?

A CH_3CH_2Br
B $CH_3CH_2CHBrCH_2CH_3$
C $(CH_3)_3CBr$
D CH_3Br

M6d-15 30 C

Nucleophilic attack by ammonia on 2-bromo-2-methylpropane, $(CH_3)_3CBr$, in a suitable solvent occurs by an S_N1 mechanism.

If the ammonia were replaced by water, the

A reaction rate would increase.
B reaction rate would decrease.
C reaction rate would be almost unaffected.
D reaction would stop.

M6d-16 50 C

$(CH_3)_3CCl$ reacts with H_2O in ethanol forming $(CH_3)_3COH$.
If OH^- were used instead of H_2O, the rate of the reaction would be

A much faster.
B much slower.
C about the same..

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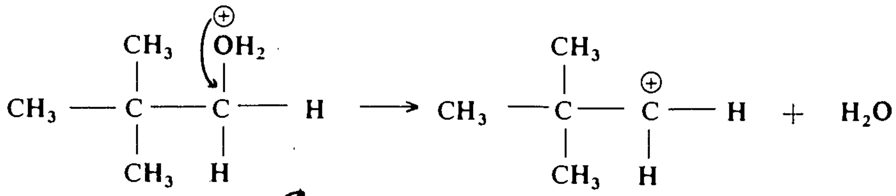
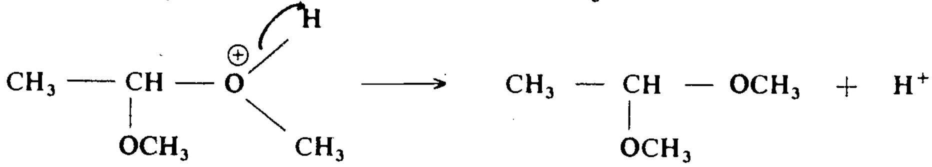
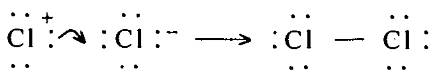
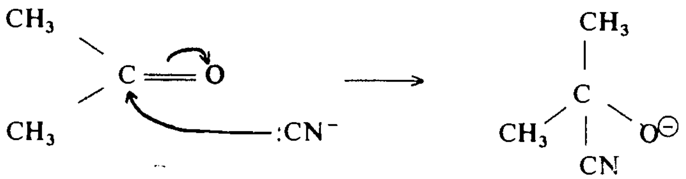
M6d-17 Which of the following equations correctly depicts the use of a curved arrow to signify the shift of a pair of electrons?
60
D

A 

B 

C 

D 

M6e Free radical reactions

M6e-1 Free radicals are best described as
70
B

A negatively charged atoms or groups of atoms with one or more extra electrons.
B neutral atoms or groups of atoms with one or more unpaired electrons.
C positively charged atoms or groups of atoms which have lost one or more electrons.
D isolated groups of atoms which are negatively charged.

M6e-2 Which of the following is a free radical?
40
D

A NO_2^+ **B** Cl_2 **C** Br^- **D** H

M6e-3 In the absence of ultraviolet light, the reaction between chlorine and ethylene, CH_2CH_2, is likely to be
40
B

A a radical reaction.
B an addition reaction.
C an electrophilic substitution.
D a nucleophilic substitution.

M6e-4 When chlorine is passed through warm benzene in sunlight a reaction occurs to produce $C_6H_6Cl_6$. Chlorine and warm benzene do not react in the absence of sunlight or ultraviolet light.
30
B

From these facts we conclude that the species attacking the benzene ring is probably

A a Cl_2 molecule. **C** a Cl^- ion.
B a Cl atom. **D** a Cl^+ ion.

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M6e-5
70
B

It has been proposed that the reaction occurring between chlorine and methane proceeds via a chain mechanism involving free radicals.

Which one of the following is a possible chain propagating step?

A $CH_3\cdot + Cl\cdot \rightarrow CH_3Cl$

B $CH_3\cdot + Cl_2 \rightarrow CH_3Cl + Cl\cdot$

C $CH_3\cdot + CH_3\cdot \rightarrow CH_3CH_3$

D $Cl_2 \rightarrow 2Cl\cdot$

M6e-6
80
C

The step $CH_3\cdot + Cl\cdot \rightarrow CH_3Cl$ in the reaction between methane and chlorine is called a

A propagating step.

B initiating step.

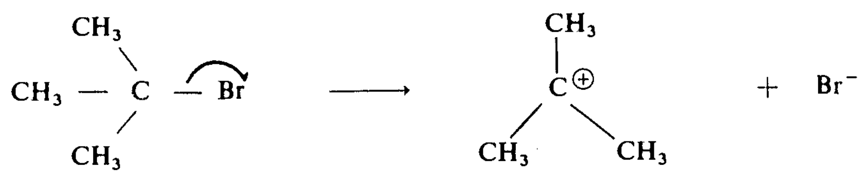
C terminating step.

D rate determining step.

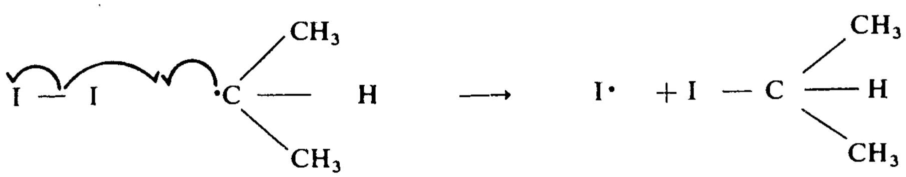
M6e-7
20
B

Which of the following equations correctly depicts the use of a single-headed curved arrow to represent the shift of an electron?

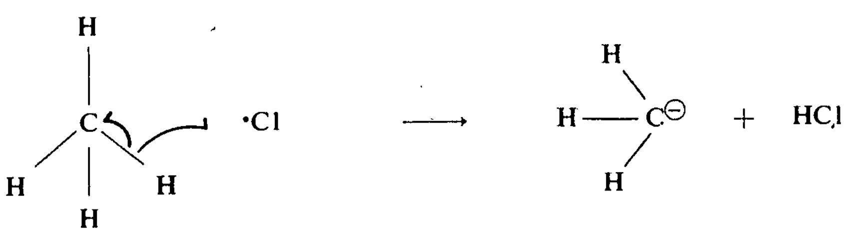
A



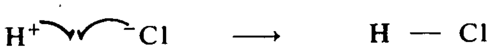
B



C



D



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N ACIDS AND BASES

N1 The acid-base concept

N1-1 70 E | Over the years, many different definitions of an acid have been proposed, some better or more complete than others. Which one of the following statements is in **no way** relevant or correct as a means of characterising an acid?

Acids

A are proton donors.
B react with metals to give a salt and hydrogen.
C neutralise bases.
D react with bases to give a salt and water.
E react with non-metals to give a salt and oxygen.

N1-2 70 D | Which one of the following is **not** a characteristic of solutions of acids?

Solutions of acids

A taste sour.
B react with zinc to form hydrogen gas.
C contain more H_3O^+ ions than OH^- ions.
D turn phenolphthalein indicator pink.

N1-3 80 B | A Bronsted base is defined as

A an electron acceptor.
B a proton acceptor.
C a substance capable of forming OH^- ions in water.
D an alkali.

N1-4 60 D | The conjugate base of the species $H_2PO_3^-$ is

A H_3PO_3.
B H_3PO_4.
C $H_2PO_4^-$.
D HPO_3^{2-}.
E HPO_4^{2-}.

The next two items refer to the following information

Consider the reactions represented by the following equations:

(i) $Zn(s) + 2H_3O^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g) + 2H_2O(l)$

(ii) $CN^-(aq) + H_3O^+(aq) \rightarrow HCN(aq) + H_2O(l)$

(iii) $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$

N1-5 80 C | Which of the reactions are acid-base?

A (i) and (ii)
B (i) and (iii)
C (ii) and (iii)
D (i), (ii), and (iii)

N1-6 80 B | In the above reactions, which of the following acts as a base?

A Zn **B** CN^- **C** H_3O^+ **D** HCN **E** H_2

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N1-7
50
D

Sulfuric acid can react with pyrosulfuric acid according to the equation

$$H_2SO_4(l) + H_2S_2O_7(l) \rightleftharpoons H_3SO_4^+(l) + HS_2O_7^-(l)$$

The species acting as acids in this reaction are

A H_2SO_4, $H_3SO_4^+$.
B $H_2S_2O_7$, $HS_2O_7^-$.
C H_2SO_4, $HS_2O_7^-$.
D $H_2S_2O_7$, $H_3SO_4^+$.

N1-8
70
B

In which one of the following equations is sulfuric acid acting as a base?

A $H_2SO_4 + 2H_2O \rightarrow 2H_3O^+ + SO_4^{2-}$
B $H_2SO_4 + H_2S_2O_7 \rightarrow H_3SO_4^+ + HS_2O_7^-$
C $H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$
D $H_2SO_4 + CH_3NH_2 \rightarrow CH_3NH_3^+ + HSO_4^-$

N1-9
60
D

Nitric acid can be prepared from the reaction of concentrated sulfuric acid with sodium nitrate.

$$NO_3^- + H_2SO_4 \rightleftharpoons HNO_3 + HSO_4^-$$

In this reaction the nitrate ion acts as

A an oxidant.
B a reductant.
C an acid.
D a base.

N1-10
70
B

In the reaction,

$$2H_2PO_4^- \rightleftharpoons H_3PO_4 + HPO_4^{2-},$$

the $H_2PO_4^-$ ion acts as

A an acid only.
B both an acid and a base.
C a reductant only.
D an oxidant only.
E both an oxidant and a reductant.

N1-11
80
C

The following half equations show ionization reactions of hydrogen sulfate:

$$H_2SO_4 \rightleftharpoons HSO_4^- + H^+$$

$$HSO_4^- \rightleftharpoons SO_4^{2-} + H^+$$

If ionization occurred in aqueous solution, the H^+ ions formed would

A remain as free protons.
B be converted to H_2 gas.
C combine with water molecules to form H_3O^+.
D force water molecules to form H^+ and OH^- ions.

N2 H_3O^+ concentration in acid solutions

N2-1
40
C

Which one of the following solutions is most highly acidic?

A hydrogen chloride in water; concentration of H_3O^+ = 0.001 M
B sodium hydroxide in water; concentration of OH^- = 0.200 M
C ethanoic (acetic) acid in water; concentration of H_3O^+ = 0.004 M
D nitric acid in water; concentration of H_3O^+ = 0.0001 M

N2-2
80
D

The sourness of a substance is a reasonable guide to its acidity—sourness increases with increasing acidity.

If solution A was more sour than solution B, then it is likely that

A solution A was at a higher pH than solution B.
B solution A has more OH^- ions in solution than solution B.
C solution A has a higher concentration of H_2O molecules than solution B.
D solution A has a higher concentration of H_3O^+ ions than solution B.

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N3 Strengths of acids and bases

N3-1 30 C
In 0.1 M HCl solution, which one of the following relationships is correct?

A $[HCl] > [H_3O^+] > [H_2O]$
B $[H_3O^+] > [HCl] > [H_2O]$
C $[H_2O] > [H_3O^+] > [HCl]$
D $[H_2O] > [HCl] > [H_3O^+]$
E $[H_3O^+] > [H_2O] > [HCl]$

N3-2 60 C
When hydrogen chloride gas dissolves in excess water, the species **least** likely to be present is

A $H_2O(l)$.
B $Cl^-(aq)$.
C $HCl(aq)$.
D $H_3O^+(aq)$.

N3-3 60* C
Which of the following best explains what occurs when pure sulfuric acid is added to water?

A The molecules of sulfuric acid and water mix without reacting.
B The sulfuric acid causes the water to ionize but it remains as H_2SO_4 molecules in the solution.
C The sulfuric acid molecules react with water molecules to form ions.
D The ions already present in the sulfuric acid lattice dissociate in water.

N3-4 50 A
Consider the equilibrium system involving the ionization of the strong acid perchloric acid:

$$HClO_4(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + ClO_4^-(aq)$$

Which of the following species would have the lowest concentration when perchloric acid is dissolved in water?

A $HClO_4$
B H_2O
C H_3O^+
D ClO_4^-

N3-5 20* B
Which of the following species is likely to be **most** abundant in 1 M NH_4Cl solution?

A NH_4^+
B Cl^-
C NH_3
D H_3O^+

N3-6 40 B
Which one of the following statements about the relative concentrations of H_2S molecules and S^{2-} ions in an aqueous solution of the weak acid hydrogen sulfide is correct?

A All the solute is present as H_2S molecules.
B The concentration of H_2S molecules is greater than the concentration of S^{2-} ions.
C The concentration of H_2S molecules is less than the concentration of S^{2-} ions.
D All the hydrogen sulfide is hydrolyzed completely to H^+ and S^{2-} ions.

The next item refers to the following solutions

Solution I hydrogen chloride gas in water; concentration of $H_3O^+ = 1 \times 10^{-4}$ M

Solution II ethanoic (acetic) acid in water; concentration of $H_3O^+ = 1 \times 10^{-4}$ M

Solution III hydrogen sulfide gas in water; concentration of $H_3O^+ = 1 \times 10^{-4}$ M

N3-7 30 D
The concentration of hydrogen chloride (as molecules of HCl) in solution I is

A greater than the concentration of ethanoic acid molecules in solution II and hydrogen sulfide molecules in solution III.
B less than the concentration of ethanoic acid molecules in solution II but greater than the concentration of hydrogen sulfide molecules in solution III.
C greater than the concentration of ethanoic acid molecules in solution II but less than the concentration of hydrogen sulfide molecules in solution III.
D less than the concentration of ethanoic acid molecules in solution II and hydrogen sulfide molecules in solution III.

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N3-8 60 **D** | A 0.1 M HCl solution has a hydrogen ion concentration of about 0.1 M, while a 0.1 M CH_3COOH (ethanoic acid) solution has a hydrogen ion concentration of about 0.001 M. The best explanation for this difference is that

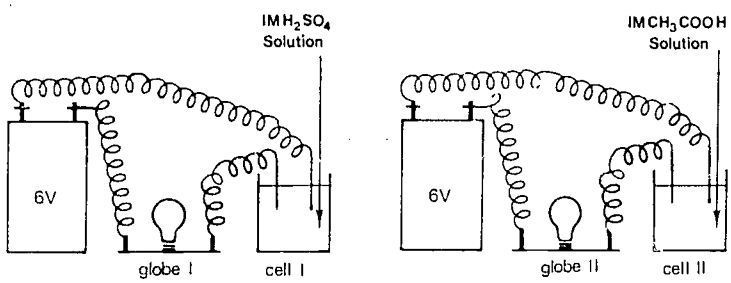
A a CH_3COOH molecule ionizes to yield more H^+ ions than an HCl molecule.

B HCl is ionic and the ions separate completely in aqueous solution, while the molecular CH_3COOH reacts only slightly with water to form ions.

C each HCl molecule ionizes completely but each CH_3COOH molecule is only partially ionized.

D as HCl donates protons more readily than CH_3COOH, a greater percentage of HCl molecules than CH_3COOH molecules will react with water to form H_3O^+ ions.

N3-9 50 **B** | An experiment to investigate the conductivity of two acids in aqueous solution was carried out, using the apparatus represented in the diagram.



Cell I contains a 1 M solution of sulfuric acid (H_2SO_4).
Cell II contains a 1 M solution of ethanoic acid (CH_3COOH).

The results obtained when the electrical circuits are completed are
(i) globe I glows brightly;
(ii) globe II glows dimly.

The best explanation of these results is that

A pure sulfuric acid is ionic and the ions separate completely in aqueous solution, whereas the molecular ethanoic acid ionizes only slightly in water.

B the proportion of ethanoic acid molecules which form ions is smaller than the proportion of sulfuric acid molecules forming ions.

C each molecule of sulfuric acid ionizes to yield three ions whereas ethanoic acid yields only two ions per molecule.

D each molecule of ethanoic acid only partially ionizes whereas each sulfuric acid molecule completely ionizes.

N3-10 60 **C** | A 100 cm^3 solution of 0.1 M HF is found to have a H^+ concentration of 8 $\times 10^{-3}$ M. However, a titration shows that 0.01 mol of OH^- is required for the neutralization of the solution. The best explanation for this is that

A the initial determination of the H^+ concentration must have been incorrect and should in fact have been 0.1 M.

B a secondary reaction between F^- and the OH^- occurs, resulting in misleading neutralization information.

C addition of the hydroxide ions causes the removal of hydrogen ions from solution and consequently HF continues to ionize.

D the presence of OH^- causes H^+ and F^- to associate and consequently changes the H^+ concentration.

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The next two items refer to the following information:

Consider the reaction between the hypothetical substances shown:

equation I, $HZ(aq) + NaY(aq) \rightarrow NaZ(aq) + HY(aq)$

and the preparation of HZ shown:

equation II, $NaZ(aq) + H_2SO_4(aq) \rightarrow NaHSO_4(aq) + HZ(aq)$

N3-11 If the reaction shown in equation I proceeds completely in the direction indicated, then it is likely that

50

A

A HZ is a stronger acid than HY and Y^- is a stronger base than Z^-.

B HZ is a stronger acid than HY and Y^- is a weaker base than Z^-.

C HZ is a weaker acid than HY and Y^- is a stronger base than Z^-.

D HZ is a weaker acid than HY and Y^- is a weaker base than Z^-.

N3-12 The reactions represented by both equations I and II proceed completely in the direction shown. Which one of the following lists shows an order of acid strength, from strongest to weakest, that corresponds with the reactions shown in equations I and II?

50

C

A HY, H_2SO_4, HZ

B HZ, H_2SO_4, HY

C H_2SO_4, HZ, HY

D HZ, HY, H_2SO_4

N3-13 When a 2 M solution of hydrochloric acid is added to a 0.1 M aqueous solution of sodium ethanoate, a vinegary smell is observed, indicating the presence of ethanoic (acetic) acid. The best explanation for this observation is that

40

A

A hydrochloric acid is a strong acid, and the ethanoate ions react with hydrochloric acid to produce the weak ethanoic acid.

B hydrochloric acid is such a strong acid that it will react with any anion to produce the corresponding acid.

C ethanoic acid is insoluble in water, and is therefore produced as a gas in the reaction.

D hydrochloric acid will always donate protons when it acts as an acid, and the ethanoate ion is the only species present in the reaction mixture capable of accepting a proton.

The next two items refer to the following information

A series of reactions was carried out between acids and sodium salts. Each reaction proceeded almost to completion. Equations for the reactions were:

$$HNO_2(aq) + OI^-(aq) \rightarrow HOI(aq) + NO_2^-(aq)$$

$$HIO_3(aq) + ClO_2^-(aq) \rightarrow IO_3^-(aq) + HClO_2(aq)$$

$$HClO_2(aq) + NO_2^-(aq) \rightarrow ClO_2^-(aq) + HNO_2(aq)$$

$$HIO_3(aq) + OI^-(aq) \rightarrow HOI(aq) + IO_3^-(aq)$$

N3-14 Which of the following is the strongest acid?

30

B

A HNO_2 B HIO_3 C $HClO_2$ D HOI

N3-15 Which of the bases is (are) stronger bases than NO_2^-?

40

B

A ClO_2^- only

B OI^- only

C IO_3^- and OI^- only

D ClO_2^- and OI_3^- only

E none of the above

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N4 Polyprotic acids

N4-1
80
D

Which one of the following acids is **not** capable of donating more than one proton?

A H_2CO_3 **B** H_3PO_4 **C** H_2S **D** HCOOH

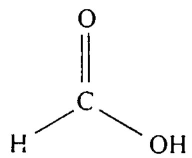
N4-2
50
B

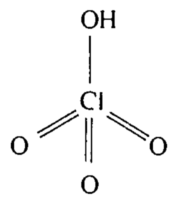
Which of the following reactions occurs to the greatest extent when orthophosphoric acid, H_3PO_4, is dissolved in water?

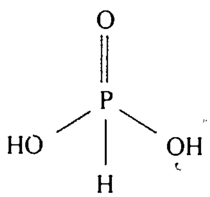
A $H_3PO_4(aq) \rightleftharpoons 3H^+(aq) + PO_4^{3-}(aq)$
B $H_3PO_4(aq) \rightleftharpoons H^+(aq) + H_2PO_4^{2-}(aq)$
C $H_2PO_4^-(aq) \rightleftharpoons H^+(aq) + HPO_4^{2-}(aq)$
D $HPO_4^{2-}(aq) \rightleftharpoons H^+(aq) + PO_4^{3-}(aq)$

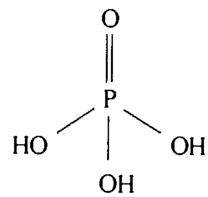
N4-3
30
B

The valence structures of several acids are drawn below. Which **acid or acids** are likely to be diprotic?

A


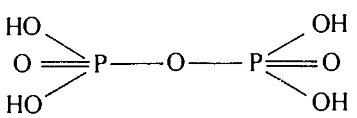
C


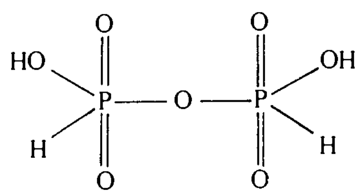
B


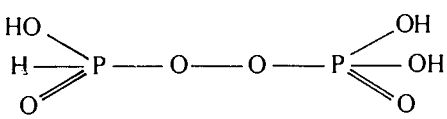
D


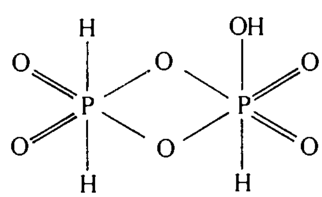
N4-4
40*
A

Pyrophosphoric acid, $H_4P_2O_7$, is a tetraprotic acid. The most likely valence structure of this acid is

A


C


B


D


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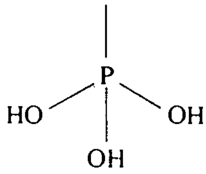
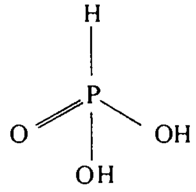
N4-5 50 B | Two possible valence structures of the acid H_3PO_3 are given below.

I



II



Experimental evidence to distinguish between the two structures would be obtained by determining

A the relative molecular mass of the acid.

B the proticity of the acid.

C the number of electrons in the outer shell of the phosphorus atom.

D the percentage, by mass, of hydrogen.

N5 Amphiprotic substances

N5-1 50 D | Which one of the following species acts as an amphiprotic species in aqueous solution?

A SO_4^{2-} B HNO_3 C PO_4^{3-}. D HCO_3^-

N5-2 70 D | Consider the reactions represented by the following equations:

$$HPO_4^{2-} + NH_4^+ \rightarrow NH_3 + H_2PO_4^-$$
$$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$$
$$HPO_4^{2-} + CN^- \rightarrow HCN + PO_4^{3-}$$
$$HCO_3^- + H_3O^+ \rightarrow 2H_2O + CO_2$$

In these reactions which one of the following reacts as an amphiprotic species?

A $H_2PO_4^-$ B NH_4^+ C CO_3^{2-} D HPO_4^{2-}

N5-3 60 B | Consider the reactions represented by

(i) $H_3PO_3 + OH^- \rightarrow H_2PO_3^- + H_2O$

(ii) $H_2PO_3^- + OH^- \rightarrow HPO_3^{2-} + H_2O$

(iii) $H_2PO_3^- + H_3O^+ \rightarrow H_3PO_3 + H_2O$

All the above reactions go to completion in the direction shown, whereas no reaction occurs if a solution of Na_2HPO_3 is treated with NaOH solution.

On the basis of this information alone, which one or more of the following entities would be considered amphiprotic?

A HPO_3^{2-} B $H_2PO_3^-$ C H_3PO_3 D H_3O^+

N6 Ionic product, K_w

N6-1 10 D | In pure water, the value of the constant K_w is numerically equal to

A $\frac{[H_3O^+][OH^-]}{[H_2O]}$.

B $\frac{[H_2O]}{[H_3O^+][OH^-]}$.

C $[H_3O^+]^2[OH^-]$.

D $[OH^-]^2$.

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N6-2 20* A | An example of a strong acid-strong base reaction is that between hydrochloric acid and sodium hydroxide in solution, as represented by the equation below.

$$NaOH(aq) + HCl(aq) \rightleftharpoons NaCl(aq) + H_2O(l) \qquad \Delta H = -57 \text{ kJ mol}^{-1}$$

Given that K_w for water is 1×10^{-14} at 25 °C, on the basis of the data given above,

A K_w at 65 °C is greater than 1×10^{-14}.
B K_w at 65 °C is less than 1×10^{-14}.
C K_w at 65 °C is 1×10^{-14}.
D the value of K_w at 65 °C may be any one of **A, B** or **C**.

N6-3 70 B | A solution is acidic if at 298 K the

A $[H^+] = 10^{-14}$ M. **C** $[H^+] = 10^{-7}$ M.
B $[OH^-] = 10^{-8}$ M. **D** $[OH^-] = 10^{-1}$ M.

N6-4 90 C | The hydrogen ion concentration in a bottle of household ammonia is 10^{-11} M. The hydroxide ion concentration will be (given $K_w = 10^{-14}$)

A 10^{-25} M. **B** 10^{-11} M. **C** 10^{-3} M. **D** 10^{3} M.

N7 pH

N7-1 50 A | The concentration of hydrogen ions in gastric juice is 0.01 M. The pH of gastric juice is

A 2.0 **C** $10^{-0.01}$
B $10^{0.01}$ **D** −2.0
E log 0.01

N7-2 90 D | A student prepares a solution that has a pH of 8·8. The concentration of H_3O^+ in the solution is

A 8·8 M. **B** 8×10^{-8} M. **C** 10^{-8} M. **D** $10^{-8.8}$ M.

N7-3 50 B | The pH of a brand of lemonade is 3.0. The concentration of hydrogen ions in solution is

A 10^{3} M. **B** 0.001 M. **C** − log 3.0 M. **D** $\frac{10^{-14}}{10^{-3}}$ M.

N7-4 50 C | If two solutions have pH values of 2 and 3, the relative concentrations of hydrogen ions in the solutions are, respectively,

A 2 : 3. **B** 1 : 2. **C** 1 : 0.1. **D** 1 : 10.

N7-5 30 A | The mass of HCl (M_r = 36.5) required to prepare 100 cm^3 of an HCl solution of pH 2.0 is

A 0.0365 g. **B** 0.365 g. **C** 7.30 g. **D** 365 g.

N7-6 40 D | A solution of HCl has a pH of 4. If the solution is diluted by a factor of 100, the pH of the resulting solution would be about

A 4×10^{-2}. **B** 4×10^{2}. **C** 2. **D** 6. **E** 8.

N7-7 20 E | What amount of gaseous HCl must be dissolved in 1 dm^3 of aqueous hydrochloric acid solution to change its pH from 3 to 2? (Assume no volume change occurs.)

A 1 mol **B** 10 mol **C** 0.01 mol **D** 0.09 mol **E** 0.009 mol

N7-8 80 A | A solution with a pH of 6 has

A a higher concentration of hydrogen ions than of hydroxyl ions.
B a lower concentration of hydrogen ions than of hydroxyl ions.
C the same concentration of hydrogen ions and hydroxyl ions.

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N7-9 50 A | A solution with a pH of -1

A is acidic.
B is neutral.
C is basic.
D does not exist.

N7-10 20 B | An attempt to prepare a NaOH solution with a pH of 16 by adding solid NaOH to a beaker of tap water would be unsuccessful because

A the pH scale does not extend beyond 14.
B insufficient OH^- ions dissolve in the water.
C acid must be added to produce this pH.
D OH^- ions react with H^+ ions present in the water.

N7-11 20* A | A solution is prepared from 20 cm^3 of 0.10 M HNO_3 and 30 cm^3 of 0.05 M H_2SO_4. If the H_2SO_4 ionizes completely, the pH of the solution would be

A +1.
B +3.
C $-\log 0.02$.
D $-\log 0.07$.

N7-12 90 A | When $Cr(NO_3)_3$ is added to water the Cr^{3+} ions react according to the equation

$$Cr^{3+} + 6H_2O \rightarrow Cr(H_2O)_6^{3+}$$

The hydrated Cr^{3+} ions then react with water according to the equation

$$Cr(H_2O)_6^{3+} + H_2O \rightleftharpoons [Cr(H_2O)_5OH]^{2+} + H_3O^+$$

The pH of a 0·1 M solution of $Cr(NO_3)_3$ is 3.

Assuming that the H_3O^+ ion in the solution is obtained only from this reaction, then the percentage of the $Cr(H_2O)_6^{3+}$ ion that has reacted with the water is

A 1 %.
B 10 %.
C 30 %.
D impossible to determine from the information given.

The next three items refer to the following key

Write: **A** if an aqueous solution of the compound has a pH greater than 7.
B if an aqueous solution of the compound has a pH less than 7.
C if an aqueous solution of the compound has a pH of approximately 7.

N7-13 80 B | HCl

N7-14 60 C | KCl

N7-15 40 A | $NaHCO_3$

N7-16 30 C | The pH of a 10^{-2} M solution of hydrochloric acid is 2, whereas a 10^{-8} M solution has a pH which is slightly less than 7. The best explanation is that

A the acid is not completely ionized at a concentration of 10^{-8} M.
B the pH of an acid must be less than 7.
C at low concentrations the dissociation of water becomes significant.
D hydroxide ions in water react with a dilute acid, lowering the concentration of hydrogen ions.

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N7-17 20* C — According to the definition of pH in terms of hydrogen ion concentration, what will be the pH of pure water at 47 °C?

(given $K_w = 4 \times 10^{-14}$ at 47 °C)

A exactly 7
B slightly higher than 7
C slightly lower than 7
D impossible to predict

N7-18 80 B — The pH of a sample of apple juice was measured as 3.0. The concentration of OH^- ions in the juice would be (given $K_w = 1.0 \times 10^{-14}$)

A 1.0×10^{-7} M.
B 1.0×10^{-11} M.
C 3.0×10^{-14} M.
D 3.3×10^{-15} M.

N7-19 80 D — One brand of lemonade has a pH of 3.0. The concentrations of hydrogen ion and hydroxide ion at 298 K in the lemonade are, respectively,

A 10^{-11} M, 10^{-3} M.
B 10^{7} M, 10^{7} M.
C 10^{3} M, 10^{11} M.
D 10^{-3} M, 10^{-11} M.

N7-20 10* B — 'Milk of magnesia' consists of a saturated solution of magnesium hydroxide, and is used to treat acid indigestion.

If the pH of milk of magnesia is 10, the concentration of $Mg(OH)_2$ in the solution is

A 1.0×10^{-4} M.
B 5.0×10^{-5} M.
C 1.0×10^{-10} M.
D 2.0×10^{-10} M.
E 5.0×10^{-11} M.

N7-21 60 B — The pH of a 0.001 M solution of sodium hydroxide at 25 °C is (given $K_w = 1.0 \times 10^{-14}$ at 25 °C)

A 3. **B** 11. **C** 12. **D** 14.

N7-22 10 C — A saturated solution of $Ca(OH)_2$ contains 5×10^{-4} mol of $Ca(OH)_2$ in 100 cm^3 of solution. The pH of this solution is
(given $K_w = 10^{-14}$)

A $-\log (10^{-14}/10^{-3})$.
B $-\log (10^{-14}/5 \times 10^{-3})$.
C $-\log (10^{-14}/10^{-2})$.
D $-\log (10^{-14}/5 \times 10^{-4})$.

N8 Stoichiometric calculations involving acid-base reactions

The next four items refer to the following information

A solution is prepared by adding 250 cm^3 of 0·05 M $Ba(OH)_2$ solution to 250 cm^3 of a 0·02 M solution of NaOH.

N8-1 50 C — The concentration of the solution with respect to the OH^- ion is

A 0·03 M. **B** 0·04 M. **C** 0·06 M. **D** 0·07 M. **E** 0·12 M.

N8-2 50 B — The concentration of the solution with respect to the Na^+ ion is

A 0·005 M. **B** 0·01 M. **C** 0·02 M. **D** 0·03 M. **E** 0·04 M.

N8-3 30 A — **What would be the minimum volume of 0·05 M H_2SO_4 required to precipitate the Ba^{2+} ions from 50 cm^3 of the solution as $BaSO_4$?**

A 25 cm^3 **B** 50 cm^3 **C** 100 cm^3 **D** 250 cm^3

N8-4 40 B — 50 cm^3 of the solution required 60 cm^3 of an HCl solution for complete neutralization.
The concentration of the HCl was

A 0·03 M. **B** 0·05 M. **C** 0·06 M. **D** 0·10 M. **E** 0·12 M.

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N8-5 30 D | The mass of anhydrous NaOH (M_r = 40) required to neutralize a mixture of 50 cm^3 of 0.30 M H_2SO_4 and 40 cm^3 of 0.10 M HCl is

A $(\frac{50 \times 0.30}{1000 \times 2} + \frac{40 \times 0.10}{1000}) \times \frac{40}{1}$ g.

B $(\frac{50 \times 0.30 \times 2}{1000} + \frac{40 \times 0.10}{1000}) \times \frac{1}{40}$ g.

C $(\frac{50 \times 0.30}{1000} + \frac{40 \times 0.10}{1000}) \times \frac{40}{1}$ g.

D $(\frac{50 \times 0.30 \times 2}{1000} + \frac{40 \times 0.10}{1000}) \times \frac{40}{1}$ g.

N8-6 30 E | Two 25.0 cm^3 samples of a NaOH solution were each neutralized in separate flasks; in the first case by 22.5 cm^3 0.1 M HCl, and in the second case by 7.5 cm^3 dilute H_2SO_4.

The concentration of the sulfuric acid is

A $\frac{22.5 \times 0.1}{25.0 \times 7.5}$ M.

B $\frac{22.5 \times 25.0}{0.1 \times 2 \times 2 \times 7.5}$ M.

C $\frac{7.5 \times 0.1 \times 25.0}{22.5 \times 2 \times 2}$ M.

D $\frac{2 \times 22.5 \times 7.5}{25.0 \times 2 \times 0.1}$ M.

E $\frac{0.1 \times 22.5}{2 \times 7.5}$ M.

N8-7 40* C | The H^+ concentration in 100 cm^3 of a 0.10 M CH_3COOH solution is 1.0×10^{-3} M. The volume of 0.20 M NaOH solution required to titrate the solution would be

A 0.5 cm^3. **B** 2.0 cm^3. **C** 50 cm^3. **D** 200 cm^3.

N8-8 10 D | The volume of 0.20 M NaOH solution required to completely react with 200 cm^3 of 0.30 M ortho-phosphoric acid, H_3PO_4, is

A 200 cm^3. **B** 300 cm^3. **C** 600 cm^3. **D** 900 cm^3.

N8-9 30 C | When phosphoric acid solution is treated with sodium hydroxide solution using phenolphthalein as an indicator, the following reactions occur

(i) $H_3PO_4 + OH^- \rightarrow H_2PO_4^- + H_2O$

(ii) $H_2PO_4^- + OH^- \rightarrow HPO_4^{2-} + H_2O$

Phenolphthalein goes pink when the second reaction is complete. What volume of 1.0 M sodium hydroxide solution must be added to 20 cm^3 of a solution containing 0.5 mol of H_3PO_4 per dm^3, and 0.5 mol NaH_2PO_4 per dm^3, to just turn the phenolphthalein indicator pink?

A 10.0 cm^3 **B** 20.0 cm^3 **C** 30.0 cm^3 **D** 40.0 cm^3 **E** 50.0 cm^3

N8-10 30* A | 20 cm^3 of 0.20 M HCl is added to 10 cm^3 of 0.10 M NaOH. The pH of the resulting solution is

A 1.0 **B** −log 0.003 **C** 3.0 **D** 7.0

N8-11 30* D | 0.050 mol of $Ba(OH)_2$ is dissolved in a 0.100 M solution of HCl.

The pH of the solution will be

A less than 7.
B equal to 7.
C greater than 7.
D impossible to determine from the information given.

N8-12 70 D | When 50 cm^3 of 1 M HCl solution reacts exactly with 50 cm^3 of 1 M NaOH solution the pH of the resulting solution is

A 0. **B** 1. **C** −log 0.5. **D** 7.

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N8-13 40* **D**

20 cm^3 of 0.20 M HNO_3 is added to 20 cm^3 of 0.10 M $Ba(OH)_2$.

The pH of the resulting solution is

A −log 0.02. **B** 0. **C** −log 0.04. **D** 7.

N8-14 40* **A**

30 cm^3 of sulfuric acid from a partially discharged car battery is just neutralized by 15 cm^3 of 0.010 M $Ba(OH)_2$ solution.

Assuming the sulfuric acid to be completely ionized, the pH of the acid in the battery is

A 2.0 **B** −log 0.005 **C** 4.0 **D** 5.0

N8-15 70* **A**

The pH of a dilute solution of a strong acid can be determined by titration using NaOH solution.

Which of the following is **not** required for the calculation of pH?

A the chemical formula of the acid
B the volume of acid used in the titration
C the volume of NaOH solution used in the titration
D the concentration of the NaOH solution

N9 Equivalence point, End point

N9-1 60 **B**

The end point in an acid-base titration is the point when

A the solution is neutral.
B the indicator changes colour.
C equal volumes of reactants have been mixed.
D reactants have been mixed in the appropriate stoichiometric ratio.

N9-2 40 **B**

A student titrated an approximately 2 M solution of ethanoic acid (CH_3COOH) into a 25.0 cm^3 sample of 2.0 M NaOH.

The equation for the reaction is

$$CH_3COOH + NaOH \rightarrow H_2O + CH_3COONa.$$

The indicator used changes colour at a pH of 7·3, while the pH of a 1 M solution of CH_3COONa is 8·5.

The equivalence point of the titration (the point where equal moles of reactants have been added) will occur

A after the end point has been reached.
B before the end point is reached.
C at exactly the same titre as the end point.
D either before or after the end point, but additional information is necessary to decide this.

N9-3 60 **D**

Vinegar consists essentially of a dilute (4-10%) solution of ethanoic acid, CH_3COOH. If vinegar is titrated with sodium hydroxide, the equivalence point is likely to occur at a pH of approximately

A 3. **B** 6. **C** 7. **D** 8. **E** 13.

N10 Sources of errors in titrations

The next three items refer to the following information

A volume of NaOH solution was pipetted into a conical flask and a few drops of phenolphthalein indicator was added. A burette was filled with standard HCl solution, and the base was titrated with the acid. This procedure was repeated three times.

The concentration of the NaOH solution was calculated on the basis of the titres obtained.

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N10-1 50 A

Which one of the following factors could be responsible for systematic errors in the analysis?

A The concentration quoted for the standard HCl solution was incorrect.

B Burette readings were estimated to the nearest tenth of the smallest scale division.

C The tap of the burette leaked during one of the titrations.

D A small quantity of base remained in the pipette tip each time it was used.

N10-2 70 C

If the pipette were always rinsed with distilled water before being filled with base, what effect would this have on the concentration calculated for the NaOH solution?

A The calculated concentration should be equal to the actual concentration.

B The calculated concentration should be higher than the actual concentration.

C The calculated concentration should be lower than the actual concentration.

N10-3 60 A

If the conical flask were always rinsed with distilled water before being filled with base, what effect would this have on the concentration calculated for the NaOH solution?

A The calculated concentration should be equal to the actual concentration.

B The calculated concentration should be higher than the actual concentration.

C The calculated concentration should be lower than the actual concentration.

N10-4 50 D

Student A standardized a sodium hydroxide solution by titrating a hydrochloric acid solution of accurately known concentration against it, with phenolphthalein as the indicator. He obtained an average titre of 18.90 cm^3 for his HCl solution.

Student **B**, using the same solutions, obtained an average titre of 19·35 cm^3.

A possible cause of this difference could be

A Student A's failure to dry the flask into which the solution was titrated.

B Student A's failure to remove traces of water from the burette by first rinsing it with the acid solution.

C Student B's failure to dry the flask into which the solution was titrated.

D Student B's failure to remove traces of water from the burette by first rinsing it with the acid solution.

N10-5 40 B

A student is attempting to determine the volume of a potassium hydroxide solution required to react with 20 cm^3 of an orthophosphoric acid solution by means of an appropriate titration.

Which one of the following would be most likely to lead to an appreciable error in his results?

A Rinsing the pipette with the orthophosphoric acid solution to be used.

B Rinsing the two titration flasks into which the acid will be pipetted with the acid solution.

C Having some water already present in the titration flasks before the acid is pipetted into them.

D Rinsing the burette with the potassium hydroxide solution to be used.

E Having four drops of phenolphthalein indicator in one titration flask and six drops in the other.

N10-6 50 D

0·80 g of sodium hydroxide (M_r = 40) was weighed from a bottle and dissolved in 15·0 cm^3 of water. This solution was then titrated with a solution of 1·0 M nitric acid. The indicator changed colour when 17·5 cm^3 of the nitric acid solution was added, instead of the expected 20·0 cm^3. This discrepancy could be explained if

A more than 15·0 cm^3 of water was added to the sodium hydroxide.

B the equivalence point of the reaction was reached before the end point.

C the actual mass of sodium hydroxide used was more than 0·80 g.

D the sodium hydroxide in the bottle had absorbed water from the air before weighing.

E the concentration of the nitric acid solution was less than 1·0 M.

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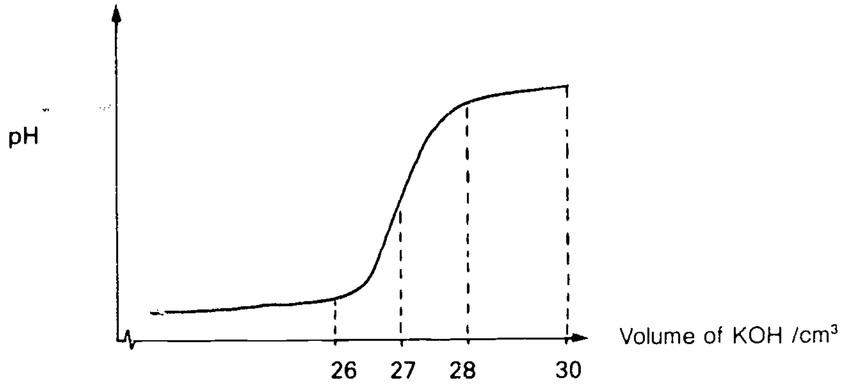
N11 Titration curves

N11-1 90 **B**

The graph below shows how the pH of an HCl solution varied as it was titrated with a KOH solution.



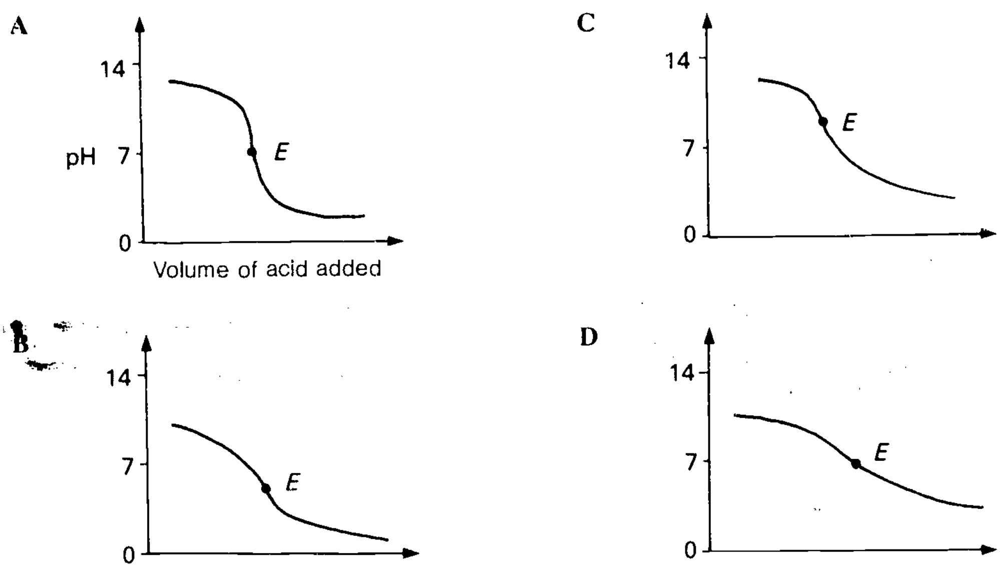
What volume of KOH solution was required to reach the equivalence point of the titration?

A 26 cm^3 **B** 27 cm^3 **C** 28 cm^3 **D** 30 cm^3

N11-2 50 **C**

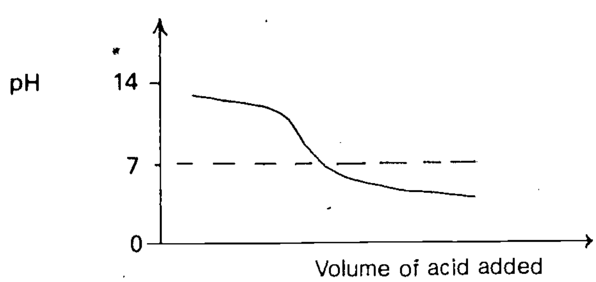
Which of the following graphs best represents the change in pH as a solution of potassium hydroxide is titrated with ethanoic acid, CH_3COOH?

(Point *E* represents the equivalence point)



N11-3 50 **A**

The graph below shows the changes in pH when a base is titrated with an acid.



The graph could correspond to the titration of

A KOH(aq) with CH_3COOH(aq).

B KOH(aq) with H_2SO_4(aq).

C NH_3(aq) with H_2SO_4(aq).

D NH_3(aq) with CH_3COOH(aq).

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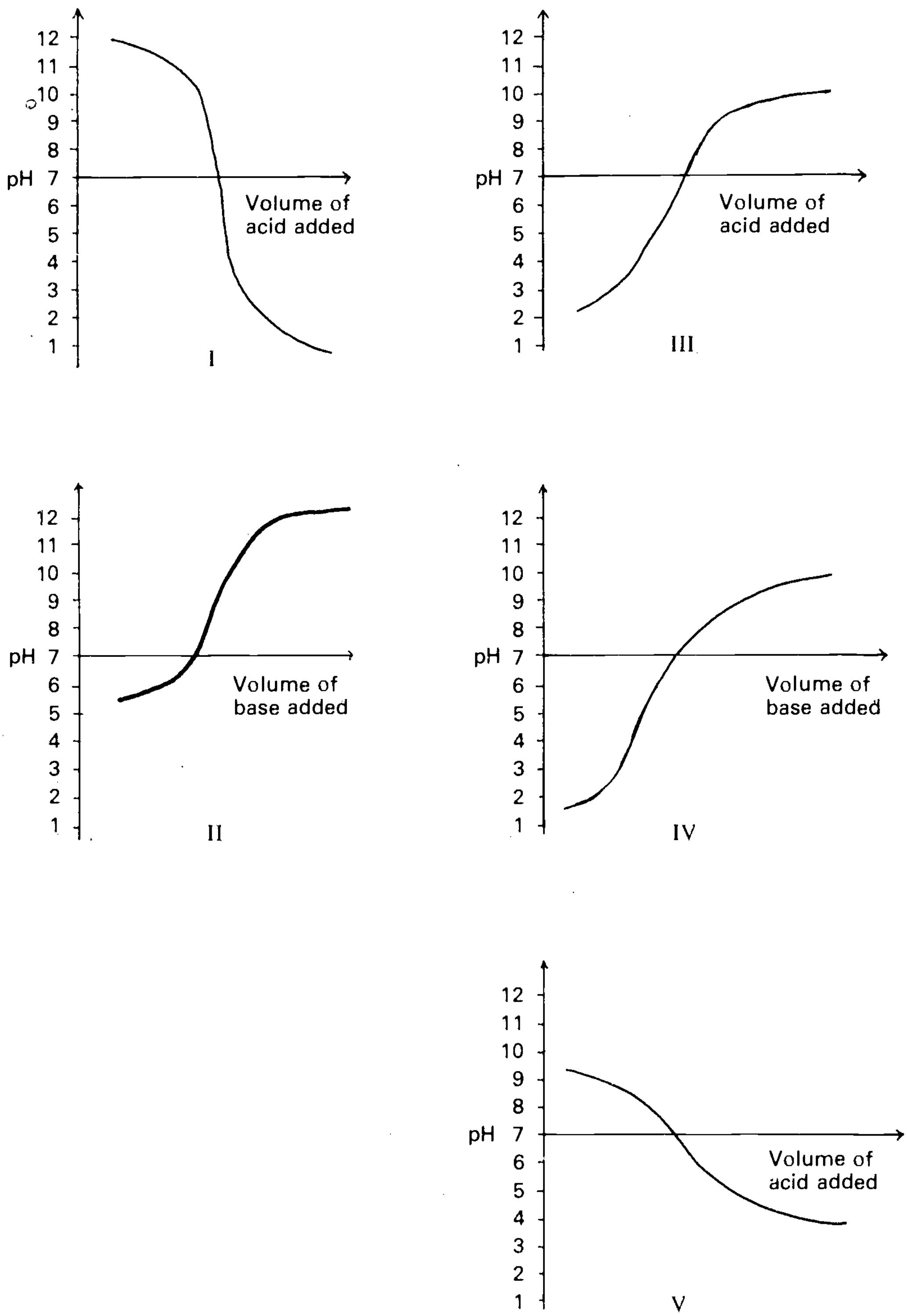
N12 Indicators

The next three items refer to the following information

The questions below refer to the titration curves I, II, III, IV and V.



N12-1 Which of the graphs is **inconsistent** with an acid-base titration?

70
C

A I **B** II **C** III **D** IV **E**. V

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N12-2
70
B

Which of the following indicators would be most appropriate for determining the end point in titration II?

A alizarin yellow R (pH range 10-12)
B cresol red (pH range 7-9)
C methyl red (pH range 3-5)
D thymol blue (pH range 1-3)

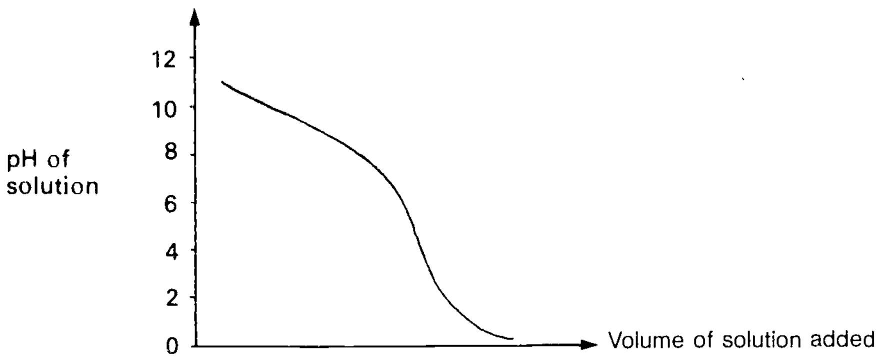
N12-3
40
A

Titration IV could correspond to the titration of

A HCl(aq) with NH_3(aq).
B CH_3COOH(aq) with NH_3(aq).
C HCl(aq) with NaOH (aq).
D CH_3COOH(aq) with NaOH(aq).

N12-4
60
B

The following graph represents the pH changes during an acid-base titration.



Four indicators, and the pH range in which their colours change, are listed below. Which one is the most appropriate for determining the end point of the above titration?

A thymol blue (pH range 1-3)
B methyl red (pH range 3-5)
C azolitmin (pH range 6-8)
D cresol red (pH range 7-9)

N12-5
50
A

The pH ranges for the colour change of four indicators are listed below.

Indicator	*pH range*
methyl orange	3.1 – 4.4
phenol red	6.8 – 8.4
phenolphthalein	8.3 – 10.0
alizarin yellow	10.1 – 12.0

The most suitable indicator to use for the titration of a sodium ethanoate solution with nitric acid is

A methyl orange.
B phenol red.
C phenolphthalein.
D alizarin yellow.

N12-6
60
D

The pK_a values of four indicators are given below.

	pK_a
thymol blue	1.7
methyl red	5.1
bromothymol blue	7.0
cresol red	8.3

The most suitable indicator to use for a titration of ethanoic acid (CH_3COOH) with sodium hydroxide solution would be

A thymol blue.
B methyl red.
C bromothymol blue.
D cresol red.

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The next four items refer to the following information

Acid-base indicators are substances which are weak acids. If such an acid is represented as HIn, it can dissociate in water according to the equation

$$HIn(aq) \rightleftharpoons H^+(aq) + In^-(aq)$$

where In^- is the conjugate base of the acid HIn. A necessary property of such an indicator is that a solution of HIn has a quite different colour from a solution of In^-. The actual colour of a solution containing a mixture of HIn and In^- will depend on the *relative* concentrations of HIn and In^- in the solution.

For a particular indicator, a solution of In^- is yellow. Furthermore, it is found that the solution appears unmistakeably red when

$$\frac{[HIn]}{[In^-]} \text{ is equal to or greater than } 10$$

and the solution is unmistakeably yellow when

$$\frac{[HIn]}{[In^-]} \text{ is equal to or less than } 0.1.$$

When $\frac{[HIn]}{[In^-]}$ is between 10 and 0.1, the solution is orange.

The magnitude of the acidity constant, K_a, of the weak acid HIn is 1×10^{-5}.

HIn is to be used as an indicator in a titration of HCl and NaOH. Since solutions containing indicator are intensely coloured, the actual concentration of the indicator present during the titration is very low indeed.

In the actual experiment a 0.200 M solution of HCl is titrated from a burette into a flask containing 10 cm^3 of 0.200 M NaOH solution and a trace of indicator solution.

N12-7 40 **D** What is the pH of the solution in the flask before the beginning of the titration?

A $-\frac{1}{2}\log(1 \times 10^{-5} \times 0.2)$
B $-\frac{1}{2}\log 0.2$
C $-\log 0.2$
D $-\log(10^{-14}/0.2)$
E $-\log(0.2 \times 10^{-14})$

N12-8 20 **D** What is the **lowest** pH at which the solution will appear unmistakeably yellow?

A 3 **B** 4 **C** 5 **D** 6 **E** 7

N12-9 20 **B** What is the **highest** pH at which the solution will appear unmistakeably red?

A 3 **B** 4 **C** 5 **D** 6 **E** 7

N12-10 70 **E** At what pH will there be exactly equal amounts of HCl and NaOH mixed, i.e. what is the pH of the equivalence point in the titration?

A 3 **B** 4 **C** 5 **D** 6 **E** 7

N13 Buffers

N13-1 60 **D** Animals and plants are protected against sharp changes in pH caused by addition of acids or bases by buffer solutions.

A buffer solution is usually composed of a mixture of

A strong acid and strong base.
B weak acid and strong base.
C strong acid and weak base.
D weak acid and weak base.

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N13-2 If equal volumes of the following pairs of solutions were mixed, which mixture would be **least** effective as a buffer?
50
D

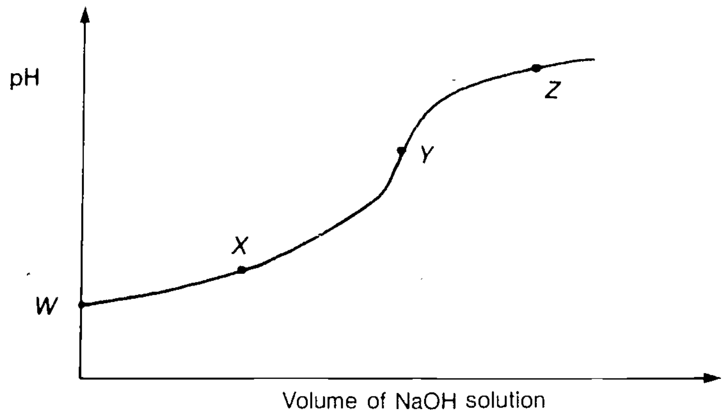
A 0.1 M $Na_2HPO_4(aq)$ and 0.1 M $NaH_2PO_4(aq)$

B 0.1 M $CO_2(aq)$ and 0.1 M $NaHCO_3(aq)$

C 0.1 M $CH_3COOH(aq)$ and 0.1 M $CH_3COONa(aq)$

D 0.1 M $HNO_3(aq)$ and 0.1 M $NaNO_3(aq)$

N13-3 The graph below shows the change in pH as a solution of ethanoic acid, CH_3COOH, is titrated with a sodium hydroxide solution.
30
B



At which stage during the titration would the mixture be the most effective buffer?

A *W* **B** *X* **C** *Y* **D** *Z*

N13-4 If a few drops of concentrated hydrochloric acid were added to a solution containing equimolar amounts of ethanoic acid and sodium ethanoate, which of the following concentrations would increase to the greatest extent?
40
A

A $[CH_3COOH]$ **B** $[H_3O^+]$ **C** $[CH_3COO^-]$ **D** $[OH^-]$

N13-5 Addition of a small volume of dilute hydrochloric acid to a mixture of solutions of ethanoic acid and sodium ethanoate has little effect on the pH because
50
C

A H^+ ions in the buffer solution restrict the degree of ionization of the dilute acid.

B the amount of H^+ ions produced by the ethanoic acid significantly exceeds that from the dilute acid.

C the ethanoate ions in the solution react with the H^+ ions from the dilute acid.

D the volume of the solution is not increased to a significant extent.

N13-6 Solutions prepared by dissolving sodium ethanoate in an ethanoic acid solution are often used in the laboratory for the calibration of pH meters.
40
D

One effect of dissolving solid sodium ethanoate in an ethanoic acid solution would be to

A lower the pH of the solution.

B lower the concentration of ethanoate ions in solution.

C leave the concentration of hydroxide ions in solution unchanged.

D raise the concentration of ethanoic acid molecules in solution.

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N14 Acidity constant, K_a

N14-1 20 **A**

Several solutions of the weak acid HCOOH were prepared by adding the acid to different volumes of water at a constant temperature.

Which one of the following ratios will be constant for all solutions when equilibrium is established?

A $\dfrac{[HCOOH]}{[H_3O^+]^2}$

B $\dfrac{[H_3O^+][OH^-]}{[HCOO^-]^2}$

C $\dfrac{[H_3O^+]^2}{[HCOOH]^2}$

D $\dfrac{[H_3O^+][HCOO^-]}{[HCOOH]^2}$

N14-2 20 **D**

For a number of different aqueous solutions of ethanoic acid at equilibrium at 25 °C, which one of the following expressions will **not** have a value constant for all solutions?

A $\dfrac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}$

B $\dfrac{[CH_3COOH][H_2O]}{[H_3O^+][CH_3COO^-]}$

C $\sqrt{\dfrac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}}$

D $\dfrac{[CH_3COOH][H_3O^+]}{[CH_3COO^-]}$

E $\dfrac{[H_3O^+]^2}{[CH_3COOH][H_2O]}$

N14-3 50 **B**

0.100 M solutions of each of the following acids were prepared. Which acid solution would have the **highest** pH?

A HOCl $K_a = 3 \times 10^{-8}$

B HCN $K_a = 5 \times 10^{-10}$

C HCOOH $K_a = 2 \times 10^{-4}$

D CH_3COOH $K_a = 2 \times 10^{-5}$

N14-4 70 **A**

The question below refers to the following information:

$$H_2C_2O_4(aq) \rightleftharpoons H^+(aq) + HC_2O_4^-(aq) \quad K_a = 6.4 \times 10^{-5} \text{ at } 25\ °C$$

A 1.0 M aqueous solution of $H_2C_2O_4$ was prepared at 25 °C. Which one of the following species was present in the greatest concentration?

A $H_2C_2O_4(aq)$ **B** $H^+(aq)$ **C** $HC_2O_4^-(aq)$ **D** $C_2O_4^{2-}(aq)$

N14-5 70 **C**

Hydrogen sulfide is a gas produced during the decay of protein. It reacts with water to form an acidic solution, according to the equation:

$$H_2S(aq) \rightleftharpoons H^+(aq) + HS^-(aq) \quad K_a = 1.0 \times 10^{-7}$$

$HS^-(aq)$ also acts as an acid. It ionizes according to the equation:

$$HS^-(aq) \rightleftharpoons H^+(aq) + S^{2-}(aq) \quad K_a = 1.2 \times 10^{-15}$$

In a saturated aqueous solution of hydrogen sulfide at room temperature, the species present in the **smallest** concentration is

A H_2S. **B** HS^-. **C** S^{2-}. **D** H^+.

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The next two items refer to the following information

20 cm^3 samples of 1.0 M aqueous solutions of each of the following acids are titrated with 1.0 M NaOH solution.

$HClO_4$	K_a greater than 10^3
HSO_4^-	$K_a = 1.0 \times 10^{-2}$
C_6H_5COOH	$K_a = 6.6 \times 10^{-5}$

N14-6 For which acid is the volume of NaOH solution required for neutralization the greatest?
20*
D

A $HClO_4$
B HSO_4^-
C C_6H_5COOH
D All four acids would be the same.

N14-7 For which acid is the quantity of heat released, per mole of water formed, the greatest?
20*
D

A $HClO_4$
B HSO_4^-
C C_6H_5COOH
D All four acids would be the same.

N14-8 Listed below are the acidity constants of four organic acids:
30*
C

Acid	K_a
CH_3COCH_2COOH	3×10^{-4}
C_6H_5COOH	6×10^{-5}
$(CH_3)_3CCOOH$	9×10^{-4}
C_6H_5OH	1×10^{-10}

The weakest base in the list below is

A $CH_3COCH_2COO^-$. **B** $C_6H_5COO^-$. C $(CH_3)_3CCOO^-$. **D** $C_6H_5O^-$.

The next three items refer to the following information

Acidity constants of some acids are:

Acid	H_2S	HS^-	$SO_2(aq)$	HSO_3^-	$CO_2(aq)$	HCO_3^-
K_a	1.0×10^{-7}	7.8×10^{-12}	0.79	1.6×10^{-7}	2.2×10^{-6}	2.1×10^{-10}

N14-9 The strongest acid in the following set is
40
C

A H_2S. **B** HS^-. C $SO_2(aq)$. **D** HSO_3^-. **E** $CO_2(aq)$.

N14-10 The strongest base in the following set is
30
B

A HS^-. **B** S^{2-}. C HSO_3^-. **D** SO_3^{2-}. **E** CO_3^{2-}.

N14-11 The weakest base in the following set is
30
C

A HS^-. **B** S^{2-}. C HSO_3^-. **D** HCO_3^-. **E** CO_3^{2-}.

The next two items refer to the following information

Hypochlorous acid, HOCl, is used to control the quality of water in some public swimming pools.

The acid reacts with water according to the equation

$$HOCl + H_2O \rightleftharpoons H_3O^+ + OCl^- \quad K_a = 4 \times 10^{-8}$$

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N14-12 70 B | The concentration of HOCl at equilibrium in a solution that is initially 0.1 M with respect to HOCl is

A 0.1 M.
B slightly less than 0.1 M.
C 4×10^{-7} M.
D 10^{-6} M.

N14-13 40 C | The concentration of H_3O^+ ions at equilibrium in a solution that is initially 0.1 M with respect to HOCl is approximately

A 0.1 M.
B 2×10^{-4} M.
C 6×10^{-5} M.
D 4×10^{-8} M.

The next two items refer to the following information.

Ethanoic acid ionizes in water according to the following reaction:

$$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$$

In a 0.100 M solution of ethanoic acid, it was found that the

$[CH_3COO^-] = 0.00133$ M.

N14-14 20 B | The K_a for ethanoic acid would be approximately

A 1.80×10^{-6}.
B 1.80×10^{-5}.
C 1.33×10^{-3}.
D 1.80×10^{-3}.

N14-15 50 C | The pH of the 0.100 M ethanoic acid solution would be closest to

A 1.
B 2.
C 3.
D 4.

The next three items refer to the following information

The acidity constant, K_a, of methanoic acid is 2×10^{-4}.

N14-16 40 B | The pH of a 0.50 M solution of methanoic acid in water would be approximately

A $-\log (0.5 \times 2 \times 10^{-4})$
B $-\log (0.5 \times 2 \times 10^{-4})^{½}$
C $0.5 \times 2 \times 10^{-4}$
D $-\log (2 \times 10^{-4})$

N14-17 40* C | Equal volumes of 0.20 M methanoic acid and 0.20 M hydrochloric acid solutions are mixed. The pH of the resulting mixture would be

A $-\log (0.1 \times 2 \times 10^{-4})^{½}$
B $-\log 0.1 - \log (0.1 \times 2 \times 10^{-4})^{½}$
C $-\log 0.1$
D $-\log 0.2 - \log (0.2 \times 2 \times 10^{-4})^{½}$

N14-18 40 C | The methanoate ion concentration in a 0.30 M solution of methanoic acid in water would be

A $-\log (0.30 \times 2 \times 10^{-4})^{½}$ M.
B $(0.30 \times 2 \times 10^{-4})$ M.
C $(0.30 \times 2 \times 10^{-4})^{½}$ M.
D $10^{-14}/(0.30 \times 2 \times 10^{-4})^{½}$ M.
E $0.30/(2 \times 10^{-4})$ M.

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