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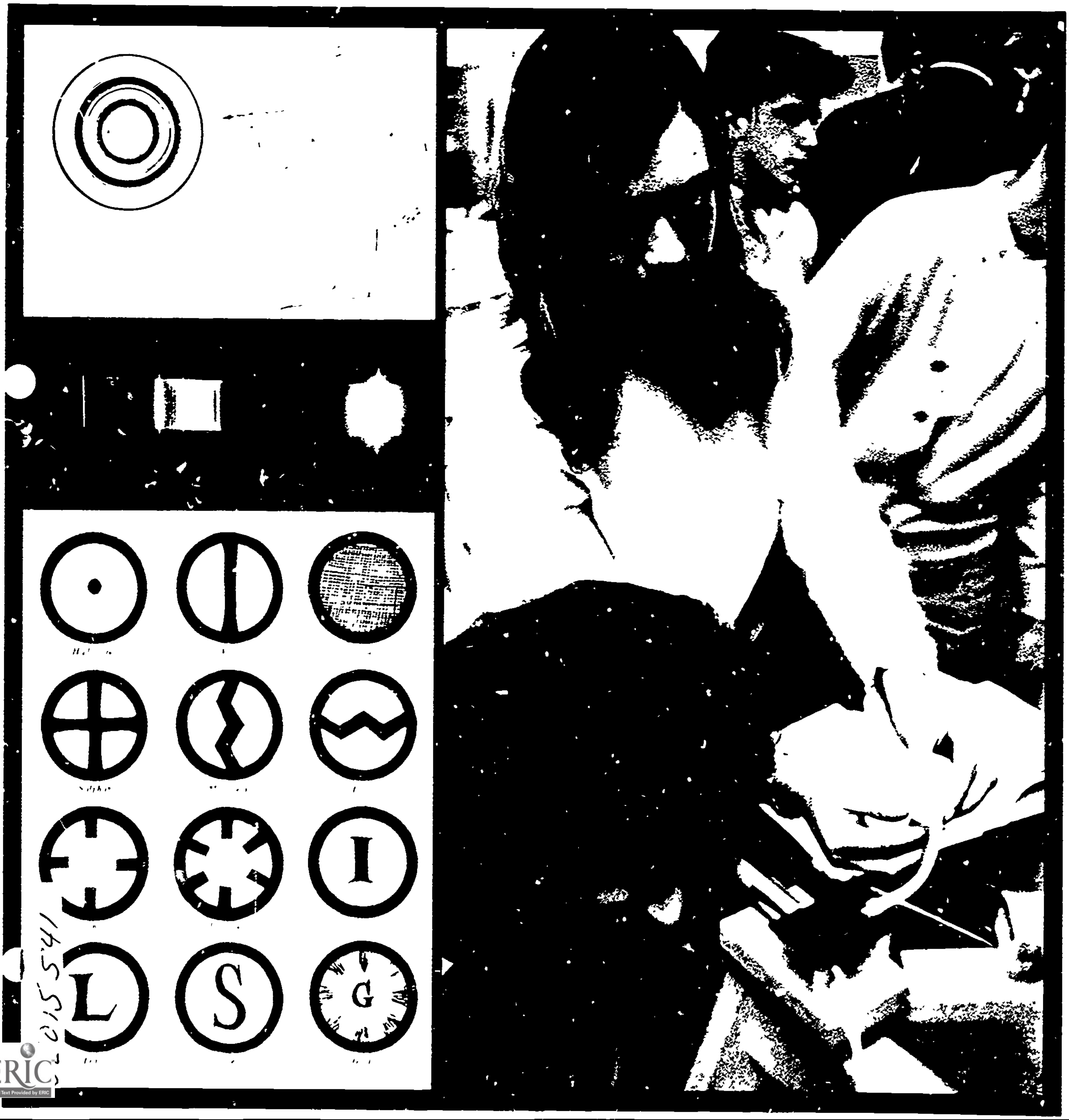
ABSTRACT

Five experiments and 19 activities are presented in this Unit 5 handbook. The experiments are related to electrolysis, charge-to-mass ratio, elementary charge determination, photoelectric effects, and spectroscopic analyses. The activities are concerned with Dalton's theory, water electrolysis, periodic tables, single-electron plating, cloud chambers, accelerators, counters, spectrographs, Einstein's work, cathode rays, x-rays, ionization, differences in atomic models, Rutherford atom, and de Broglie waves. A reprinted chemi-crostic and a specially designed cigar box atom are also incorporated in the activities. Moreover, three film loops are introduced in terms of production of sodium electrolysis, Thomson's atomic model, and Rutherford scattering. Demonstrations, construction projects, and self-directed instructions are stressed in the activities. The four chapters in the handbook are designed to correspond to the text, with complete instructions in each experiment. Some experiments and activities are suggested for assignment, and the remaining are used at student discretion. Illustrations are provided for explanation purposes. The work of Harvard Project Physics has been financially supported by: the Carnegie Corporation of New York, the Ford Foundation, the National Science Foundation, the Alfred P. Sloan Foundation, the United States Office of Education, and Harvard University. (CC)

Project Physics Handbook 5

An Introduction to Physics

Models of the Atom



This handbook is the authorized interim version of one of the many instructional materials being developed by Harvard Project Physics, including text units, laboratory experiments, and teacher guides. Its development has profited from the help of many of the colleagues listed at the front of the text units.

The work of Harvard Project Physics has been financially supported by the Carnegie Corporation of New York, the Ford Foundation, the National Science Foundation, the Alfred P. Sloan Foundation, the United States Office of Education and Harvard University.

Consult the Project Physics text for a partial list of the current and recent staff, consultants and advisory committee.

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Project Physics **Handbook**

An Introduction to Physics 5 Models of the Atom

Authorized Interim Version 1968-69

Distributed by Holt, Rinehart and Winston, Inc. New York Toronto

Chapter 17 The Chemical Basis of Atomic Theory

Chapter 18 Electrons and Quanta

Chapter 19 The Rutherford—Bohr Model of the Atom

Chapter 20 Some Ideas From Modern Physical Theories

This Student Handbook is different from laboratory manuals you may have worked with before. There are far more things described in this handbook than any one student can possibly do. Only a few of the experiments and activities will be assigned. You are encouraged to pick and choose from the rest any of the activities that appear interesting and valuable for you. A number of activities may occur to you that are not described in the handbook and that you would prefer to do instead. You should feel free to pursue these in consultation with your teacher.

There is a section corresponding to each chapter of the text. Most sections are composed of two major subsections—Experiments and Activities.

The Experiments section contains complete instructions for the experiments your class will be doing in the school laboratory. The Activities section contains suggestions for demonstrations, construction projects and other activities you can do by yourself. (The division between Experiments and Activities is not hard and fast; what is done in the school laboratory and what is done by the student on his own may vary from school to school.)

The Film Loop Notes give instructions for the use of the film loops which have been prepared for this course.

EXPERIMENT 41 Electrolysis

Volta and Davy discovered that electric currents can create chemical changes never observed before. They were the first to use electricity to break down stable compounds and to isolate new chemical elements.

But that was not all.

Later Faraday and other experimenters compared the amount of electric charge used and the amount of chemical products formed. Their measurements fell into a regular pattern that hinted at some underlying link between electricity and matter.

In this experiment you will use an electric current to decompose a compound, comparing the charge used with the mass of one of the products. From these results you can compute the mass and volume of an atom of the product.

Background

A beaker of copper sulfate ($CuSO_4$) solution in water is supported under one arm of a balance (Fig. 1). One copper electrode, the cathode, is supported in the solution by the balance arm so that you can measure its mass without removing it from the solution. A second copper electrode, the anode, fits against the inside wall of the beaker.

Electric current is provided by a power supply that converts 110-volt alternating current into low voltage direct current. The current is controlled by a variable transformer (or a rheostat) and measured by an ammeter in series with the electrolytic cell as shown in Fig. 1 or Fig. 2.

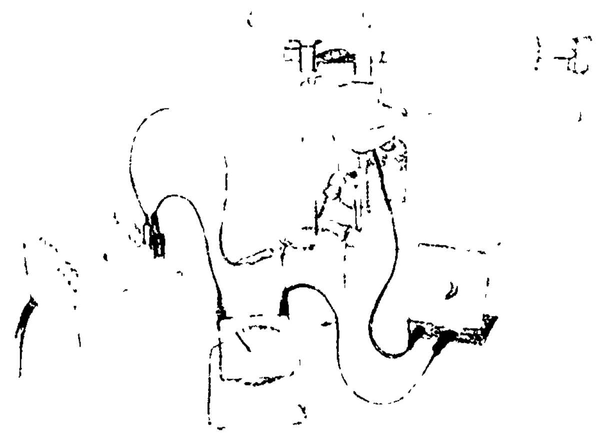


Fig. 2

As long as there is current in the cell you can observe the increasing mass of the cathode as copper forms on it. With the help of a watch to measure the time the current flows, you can compute

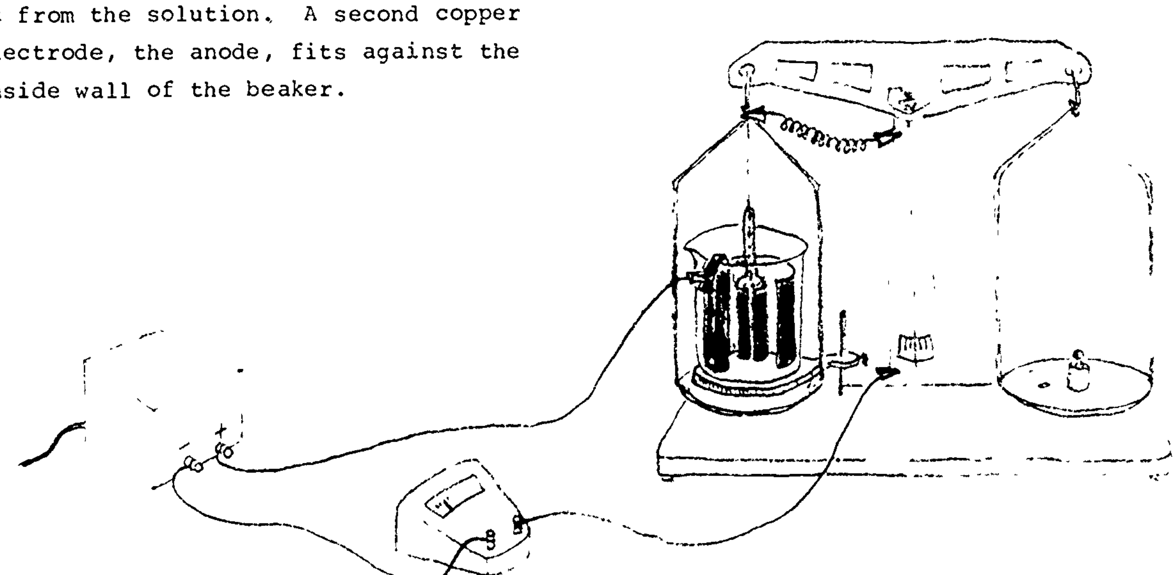


Fig. 1

the electric charge, $q = I \times t$, that passed through the cell.

If you know the amount of charge carried by a single electron (1.6×10^{-19} coulombs), you can calculate the number of electrons transferred. From number of of electrons transferred, the total mass of copper deposited, and the number of electrons required to release one copper atom from solution, you can calculate the mass of a single copper atom.

Procedure

Either an "equal-arm" or a "triple-beam" balance can be used for this experiment. Arrange the cell and the balance as shown in the appropriate figure. The cathode cylinder must be supported far enough above the bottom of the beaker so that the balance arm can move up and down freely when the cell is full of the copper-sulfate solution.

Next connect the circuit as illustrated in the figure. Note that the electrical connection from the negative terminal of the power supply to the cathode is made through the balance beam. The knife edge and its seat must be bypassed by a short piece of thin flexible wire, as shown in Fig. 1 or Fig. 3. The positive terminal of the power supply is connected directly to the anode in any convenient manner

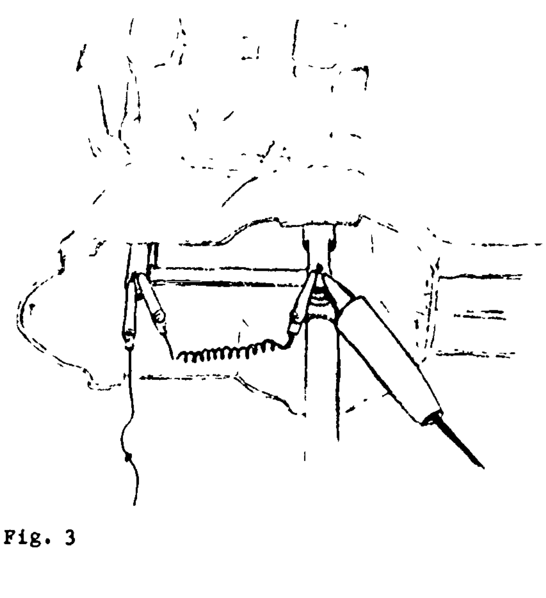


Fig. 3

Before any measurements are made, operate the cell long enough (10 or 15 minutes) to form a preliminary deposit on the cathode—unless this has already been done. In any case, run the current long enough to set it at the value recommended by your instructor, probably about 5 amperes.

When all is ready, adjust the balance and record the reading. Pass the current for the length of time recommended by your instructor. Measure and record the current, I, and the time during which the current passes, t. Check the ammeter occasionally and, if necessary, keep the current set to its original value by adjusting the rheostat or variable transformer.

At the end of the run, reset the balance and record the new reading. Find by subtraction the increase in mass of the cathode. Also record the current I.

Since the cathode is buoyed up by a liquid, the masses you have measured are not, unfortunately, the true masses. Because of the buoyant force exerted by the liquid, the mass of the cathode and its increase in mass, Δm, will both appear to be less than they would be in air. To find the true mass increase, Δm, we must divide the observed mass increase by the factor $(1 - D_e/D_c)$, where D_e is the density of the electrolyte and D_c is the density of the copper.

Your instructor will give you the values of these two densities if you cannot measure them for yourself. He will also explain how the correction factor is derived. The important thing for you to understand here is why a correction factor is necessary.

Results

Q1 How much charge was transferred to the cathode?

In the solution this positive charge is carried from anode to cathode by doubly charged copper ions, Cu^{++}. At the cathode the copper ions are neutralized by electrons and neutral copper atoms are deposited.

Q2 How many electrons (single negative charge) are required to neutralize each copper ion?

Q3 How many electrons were required to neutralize the total charge transferred? (Each electron carries -1.6×10^{-19} coulomb.)

Q4 How many copper atoms were deposited?

Q5 What is the mass of each copper atom?

Q6 The mass of a penny is about 3 grams. If it were made of copper only, how many atoms would it contain? In fact modern pennies contain zinc (5%) as well as copper.

Q7 The volume of a penny is about 0.3 cm^3. How much volume does each atom occupy?

Q8 You may have learned the concept of gram-atomic weight. The atomic weight of copper is 63.5. How many atoms are there in one gram atomic weight?

If you repeated this experiment with a different solution and made a deposit of say, silver, you could determine the mass and approximate size of a silver atom. But the answer to the last question "How many atoms in one gram atomic weight?" would be the same. It is the same for all the elements.

ACTIVITY Dalton's puzzle

Once Dalton had his theory to work with, the job of figuring out relative atomic masses and empirical formulas boiled down to nothing more than working through a series of puzzles. Here is a very similar kind of puzzle with which you can challenge your classmates.

Choose three sets of objects, each set having a different mass. Large ball bearings of about 70, 160, and 200 grams mass work well. Let the smallest one represent an atom of hydrogen, the middle-sized one an atom of nitrogen, and the large one an atom of oxygen.

From these "atoms," construct "molecules" by concealing combinations of atoms in covered styrofoam coffee cups (or other light, opaque containers). For example, NH_3 would be represented by three small objects and one middle-sized one, N_2O by two middle-sized ones and one large, and so forth. Label the "compounds" A, B, etc., and mark on each the symbols (with either present-day symbols or Dalton's ideographs) of the elements contained in the compound. Dalton would have obtained this information by qualitative analysis.

Give the covered cups to other students. Instruct them to measure the mass of each compound and to deduce the relative atomic masses and empirical formulas from the set of masses, making Dalton's assumption of simplicity. If the objects you have used for "atoms" are so light that the mass of the styrofoam cups must be taken into account, you can either supply this information as part of the data or leave it as a complication in the problem (a complication that Dalton didn't have to deal with).

If the assumption of simplicity is relaxed, what other atomic masses and molecular formulas would be consistent with the data?

ACTIVITY The electrolysis of water

The fact that electricity can decompose water was an amazing and exciting discovery, yet the process is one that you can easily demonstrate with materials at your disposal. Figure 17.2 on page 28 provides all the necessary information. Set up an electrolysis apparatus and demonstrate the process for your classmates.

In Fig. 17.2, it looks as if twice as many bubbles were coming from one electrode (which one?) as from the other. Does this happen in your apparatus? Would you expect it to?

What are the two gases that bubble off the electrodes? Can you prove their identity? Devise a method for collecting the products of the electrolysis. Is water really just these two gases "put together" chemically? If so, can you put the gases together again and get back the water you started with? What happens to all the electricity you sent flowing through the water?

What made this simple process so amazing when it was first observed? Why wasn't it observed earlier? After all, experiments with electricity had been going on since ancient times.

ACTIVITY Periodic table

You may have seen one or two forms of the periodic table in your classroom, but many others have been devised to emphasize various relationships among the elements. Some, such as the one on the next page, are more visually interesting than others. Check various sources

Activities

OUR HERITAGE OF THE ELEMENTS

Adapted from a speech delivered before the American Society for Metals, Metals-Materials Congress, Philadelphia, Pa. October 19, 1964

Reprinted from Chemistry, July 1966.

in your library and prepare an exhibit of the various types. An especially good lead is the article, "Ups and Downs of the Periodic Table" in Chemistry, July 1966 which shows 12 different forms of the table.

It is also interesting to arrange the elements in order of discovery on a linear time chart. Periods of intense activity caused by breakthroughs in methods or extended work by a certain group of investigators show up in groups of names. A simple way to do this is to use a typewriter, letting each line represent one year (from 1600 on). All the elements then fit on six normal typing pages which can be fastened together for mounting on a wall. A list of dates for all elements is on pages 48 and 49 of the Unit 6 text.

ACTIVITY **Single-electrode plating**

A student asked if copper would plate out from a solution of copper sulfate if only a negative electrode were placed in the solution. It was tried and no copper was observed even when a high voltage was applied. Another student suggested that only a very small (i.e., invisible) amount of copper was deposited since copper ions should be attracted to a negative electrode.

A more precise test was devised. A nickel sulfate solution was made containing several microcuries of radioactive nickel (no radio-copper was available). A graphite electrode was immersed in the solution, and a high negative voltage applied for five minutes. The electrode was removed, dried, and tested with a Geiger counter. The rod was slightly radioactive. A control test was run using identical test conditions, except that NO voltage was applied to the electrode. The control showed MORE radioactivity.

Repeat these experiments and see if the effect is true generally. What explanation would you give for this effect? (Adapted from Ideas for Science Investigations, N.S.T.A. 1966).

ACTIVITY **Activities from *Scientific American***

The following articles from the "Amateur Scientist" section of Scientific American relate to Unit 5. They range widely in difficulty. Each listing has title, year, month and page number.

Accelerator, electron, 1959 Jan. 138.

Beta ray spectrometer, 1958 Sept. 197.

Carbon 14 dating, 1957 Feb. 159.

Cloud chamber, diffusion, 1952 Sept. 179.

Cloud chamber, plumber's friend, 1956 Dec. 169.

Cloud chamber, Wilson, 1956 Apr. 156.

Cloud chamber, with magnet, 1959 June 173.

Cyclotron, 1953 Sept. 154.

Gas discharge tubes, how to make, 1958 Feb. 112.

Geiger counter, how to make, 1960 May 189.

Isotope experiments, 1960 May 189.

Magnetic resonance spectrometer, 1959 Apr. 171.

Scintillation counter, 1953 Mar. 104.

Spectrograph, astronomical, 1956 Sept. 259.

Spectrograph, Bunsen's, 1955 June 122.

Spinthariscope, 1953 Mar. 104.

Spectroheliograph, how to make, 1958 Apr. 126.

Subatomic particle scattering, simulating, 1965 Aug. 102.

FILM LOOP 46 Production of Sodium by Electrolysis

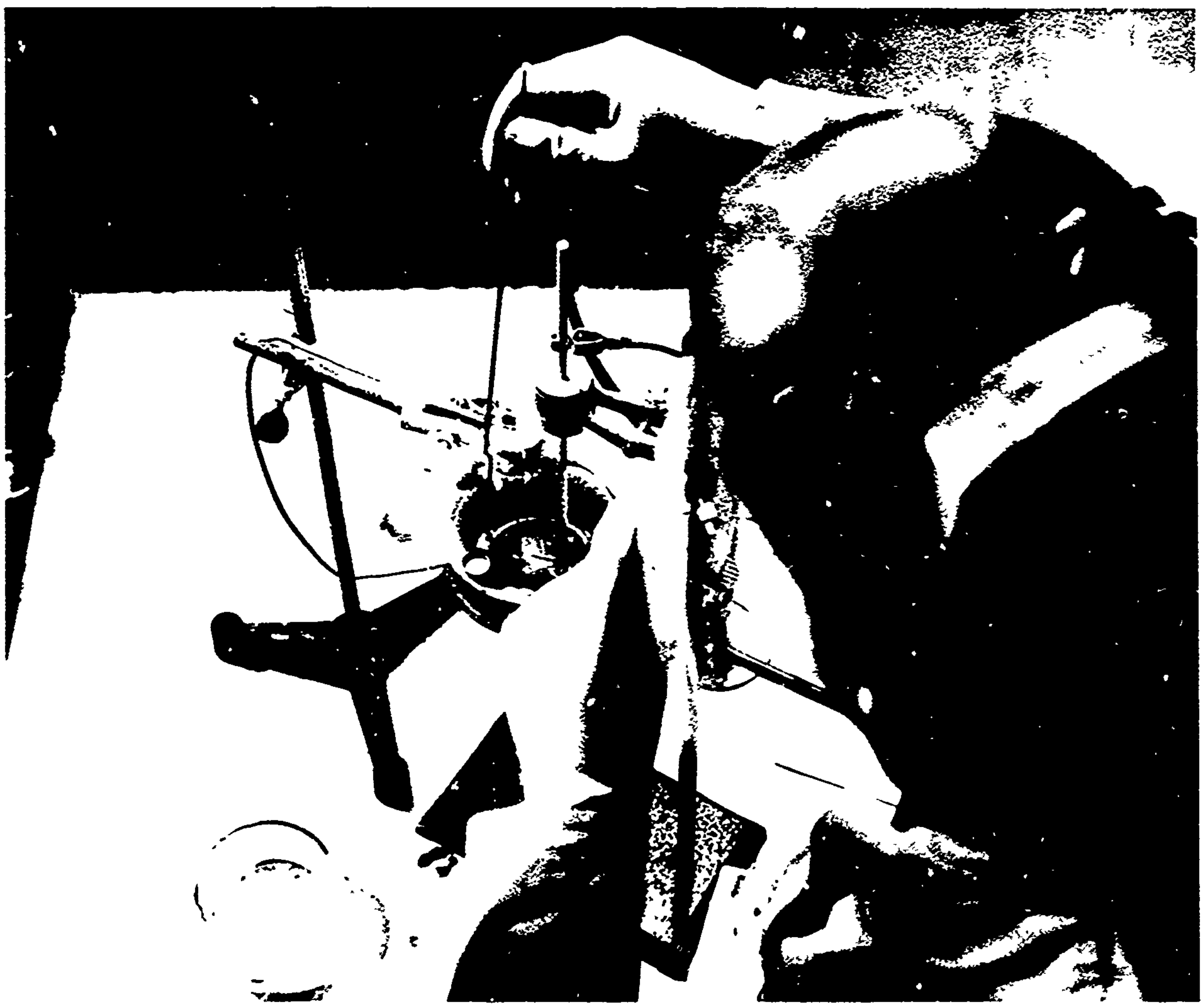
Humphrey Davy in 1807 first produced metallic sodium by electrolysis of soda (sodium hydroxide). The film shows how this is done.

First, sodium hydroxide (NaOH) is placed in an iron crucible and heated with a gas flame until it becomes molten at a temperature of 318° C. Then, iron rods to serve as electrodes are inserted into the melt. A rectifier circuit connected to a power transformer supplies a steady current through the liquid NaOH. Sodium ions are positive and are therefore attracted to the negative electrode; there they pick up negative charges (electrons) and become metallic sodium:

$$Na^{+} + e^{-} \cdot Na.$$

The sodium accumulates in a thin shiny layer floating on the surface of the liquid.

Sodium is a dangerous material which combines explosively with water. When the experimenter scoops out a little of the metal and places it in water, energy is released rapidly. Some of the sodium is vaporized and emits the yellow light characteristic of the spectrum of sodium. The same yellow spectrum is easily seen if common salt (NaCl) or some other sodium compound is sprinkled into an open flame.



EXPERIMENT 39 The Charge-to-Mass Ra.io for an Electron

In Sec. 18.2 of the text you can read about J. J. Thomson's work on cathode rays. If you did Experi-ent 37 in Unit 4, "Electron Beam Tube," you have already done some work with cathode rays and have seen how they can be deflected by electric and magnetic fields. In this experiment you will be able to repeat Thomson's quantitative measurements that convinced physicists that the rays are charged particles, each with the same ratio of charge to mass.

For the version of the experiment described here, you will use your own electron beam tube. There are other methods not described here that you may wish to try. Ask your instructor for details.

Electron-beam tube

You will need a tube that gives an electron beam at least 5 cm long. If you kept the tube you made in Experiment 37, you may be abl to use that. If your class didn't have much success with t experiment, it may mean that your vacuum pump is not working well enough, in which case you will probably decide to use another method.

Thomson's method is summarized on page 41 of Unit 5, and you should read that section of the text before beginning this experiment.

The magnetic field

In this experiment you need to be able to adjust the strength of the magnetic field until the magnetic force on the charges just balances the force due to the electric field. To enable you to change the magnetic field, you will use a pair of coils instead of permanent magnets. You can vary the magnetic field by changing the current in the coils.

Take a cardboard tube about 3" in diameter and 3" long. Cut a slot 1¼" wide in it. Your electron-beam tube should fit into this slot (Fig. 1).

Now wind a pair of coils, one on each side of the slot. Use insulated copper wire (magnet wire). Use about 20 turns of wire for each of the two coils, one coil on each side of the slot. Make the coils as neat as you can and keep them close to the slot. Wind both coils in the same sense (that is, both clockwise) and use one piece of wire for both coils. Leave about 10" of wire free at both ends of the coil. (Don't cut the wire off the reel until you have found how much you'll need!)

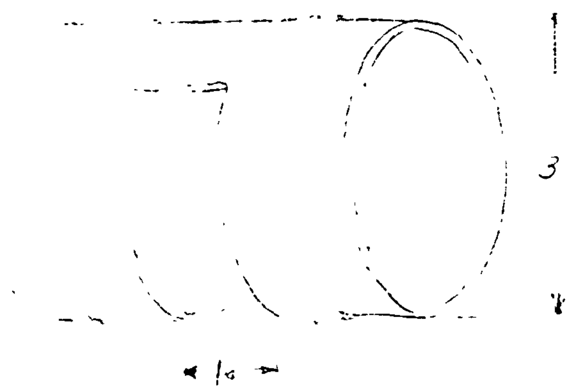


Fig. 1 Sketch of coils

Now that you have made your magnet, you must calibrate it. You can use the current balance, as you did in Experiment 36. Use the shortest of the balance "loops" so that it will fit inside the coils as shown in Fig. 2.

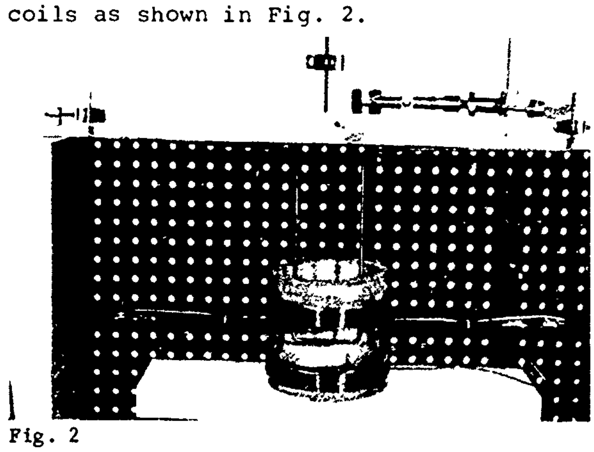


Fig. 2

Experiments

Measure the force F for a current I in the loop. Use $F = BIl$ to calculate the magnetic field due to the current in the coils. Do this for several different values of current in the coil and plot a graph of magnetic field B against coil current I.

Experimental

Set up your beam tube as in Experiment 37.

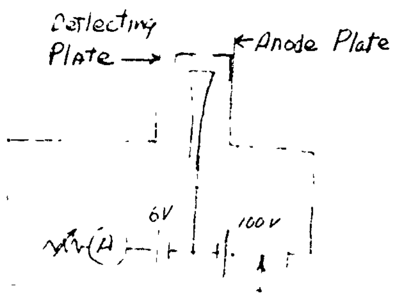


Fig. 3 Connections of beam tube

Pump it out and adjust the filament current until you have an easily visible beam. Connect a wire between the pin for the deflecting plate and the pin for the anode plate. There is now no field between the plates and the electron beam should go straight up the center of the tube between the two plates; if it does not, it is probably because the filament and the hole in the anode are not properly aligned.

Now, without releasing the vacuum, mount the coils around the tube as shown in Fig. 4.

Connect the two leads from your coils to a power supply capable of giving up to 5 amps direct current. There must be a rheostat in the circuit to control the current and an ammeter to measure it.

Now put a potential difference of about 100 volts between the anode plate and the deflecting plate, to deflect the beam as in Fig. 18.4 (c). Observe which way the beam is deflected.

Fig. 4 The magnetic field is parallel to the axis of the coils; the electric and magnetic fields are perpendicular to each other and to the electron beam.

Turn off the electric field (by making both anode and deflecting plates the same potential). Turn on and slowly increase the current in the coils until the magnetic field is strong enough to deflect the electron beam noticeably. This deflection must be opposite to the deflection caused by the electric field. You may have to reverse the direction of the current in the coils.

Now turn the electric field on again. Which field has the greater effect on the beam—the electric or the magnetic? Adjust the magnetic field by controlling the current in the coils until the effects of the two fields balance each other and the electron beam goes straight along the middle of the tube.

Record the current in the coils, and the potential difference between the deflecting plate and anode plate. You can find the magnetic field B from your calibration graph of coil current vs. B.

You need to know one more quantity

before you can calculate q_e/m. This is R, the radius of the arc which the electron beam is bent into by the magnetic field alone. To find R, turn off the electric field again, but leave the magnetic field on with the same current in the coils. Observe the deflection of the beam due to the magnetic field alone. The magnetic field is uniform in the region between the coils and so this curved arc should be circular. You won't be able to measure the radius directly, but here is one way you can do it from measurements that are easy to make:

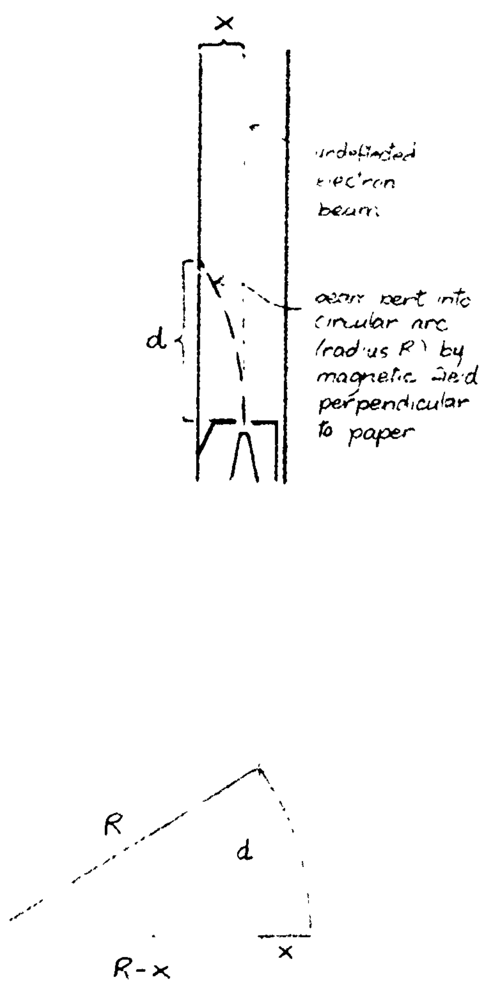


Fig. 5

You can measure x and d. It follows from Pythagoras' theorem that $R^2 = d^2 + (R - x)^2$, so $R = \frac{d^2 + x^2}{2x}$.

Now you can use the formula $q_e/m = E/B^2R$, obtained by equating the magnetic and electric forces on the charges, to calculate your value of q_e/m.

If possible you should find other pairs of values of E and B which leave the beam undeflected, measure R for each value of B and calculate more experimental values for q_e/m.

EXPERIMENT 40 The Measurement of Elementary Charge

In this experiment you are going to measure very small electric charges to see if there is a limit to how small an electric charge can be. Try to answer these three questions before you begin to do the experiment in the lab.

Q1 What is the electric field between two parallel plates separated by a distance d meters, if the potential difference between them is V volts?

Q2 What is the electric force on a particle carrying a charge of q coulombs in an electric field of E volts/meter?

Q3 What is the gravitational force on a particle of mass m in the earth's gravitational field?

Background

This experiment is substantially the same as Millikan's famous oil-drop experiment, described on page 43 of Unit 5. The following instructions assume that you have read that description.

We measure electric charges by measuring the forces they produce and experience. The extremely small charges which interest us require that we measure extremely small forces. Objects on which such small forces can have a visible effect must also in turn be very small.

Millikan used the electrically charged droplets of oil in a fine spray. Such droplets vary in size, which complicated his measurements. Fortunately we now have available suitable objects whose sizes are accurately known. We use small latex spheres (about 10^{-4} cm diameter) which are in any given sample almost identical in size. In fact, these spheres, shown magnified in Fig. 1, are used by electron microscopists to find the magnification of their instruments. The spheres can be bought in a water suspension,

Fig. 1 Electron micrograph of latex spheres 1.099μ in diameter (~ 1.1×10^{-4} cm), silhouetted against diffracting grating of 28,800 lines/inch. (Courtesy L. J. Lippie Dow Chemical Company, Midland, Michigan.)

with their diameter recorded on the bottle. When the suspension is sprayed into the air the water quickly evaporates and leaves a cloud of these particles in the air. They become charged by friction during the spraying. In the space between the plates of the Millikan apparatus they appear through the 50-power microscope as bright points of light against a dark background.

Since the electric field between the plates can pull them upwards against the force of gravity, we know the spheres in the spray are charged electrically.

In our experiment we adjust the electric field until a sphere hangs motionless. Then we know that the upward electric force on it, Eq, is exactly equal to the downward gravitational force, ma_g. We know the electric field strength, E, from the potential difference and the plate separation: $E = \frac{V}{d}$. We also know the mass m of the sphere (all the spheres have the same size and mass). We can then easily solve the equation, equating the electric to the gravitational force, $Eq = ma_g$, for the charge on the sphere, q.

Using the apparatus

If the apparatus is not already in working order, consult your instructor. Study Fig. 2 until you can identify the various parts. Then switch on the light source and look through the microscope. You should see a series of lines in clear focus against a uniform, light gray background.

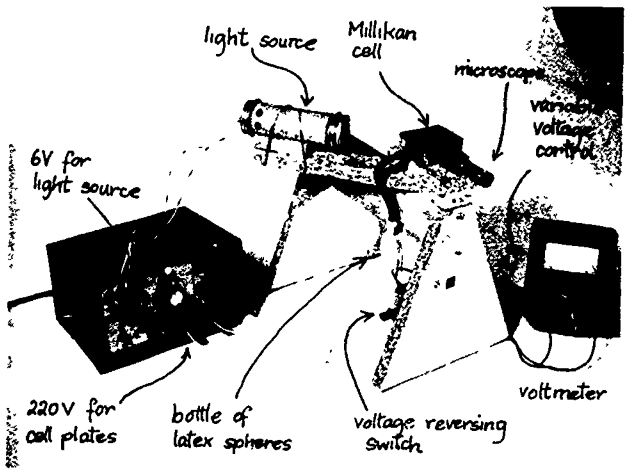


Fig. 2(a)

The lens may mist up as the heat from the lamp drives moisture out of the light-source tube. If this happens remove the lens and wipe it on a clean tissue. Wait for the tube to warm up thoroughly before replacing the lens.

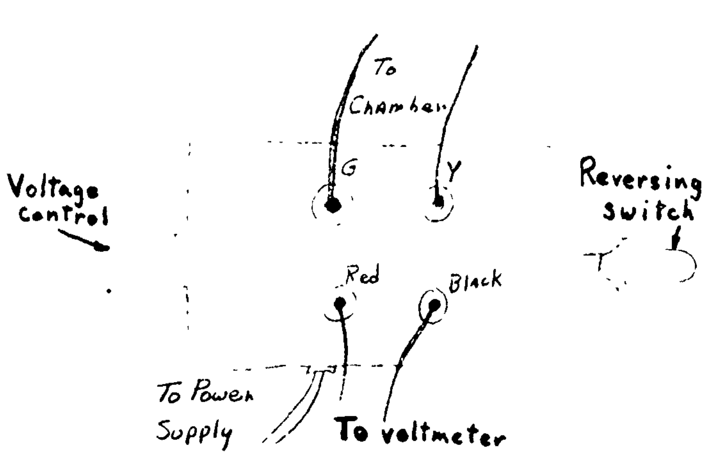


Fig. 2(b)

Squeeze the bottle of latex suspension two or three times until five or ten particles (latex spheres) drift into the view seen through the microscope. You will see them as tiny bright spots of light. You may have to adjust the focus slightly to see a specific particle clearly. Notice how the particles appear to move upward. The view is inverted by the microscope—the particles are actually falling in the earth's gravitational field.

Now switch on the high voltage across the plates by turning the switch up or down. Notice the effect on the particles of varying the electric field by means of the voltage-control knob.

Notice the effect when you reverse the electric field by reversing the switch position. (When the switch is in its mid-position, there is zero field between the plates.)

Q4 Do all the particles move in the same direction when the field is on?

Q5 How do you explain this?

Q6 Why do some move much more rapidly in the field than others?

Q7 Do the rapidly moving particles have larger or smaller charges than the slowly moving ones?

Sometimes a few particles cling together, making a clump that is easy to see—the clump falls more rapidly than single particles when the electric field is off. Do not try to use these for measuring q.

Try to balance a particle by adjusting the field until the particle hangs motionless. Observe it carefully to make sure it isn't slowly drifting up or down. The smaller the charge, the greater the electric field must be to hold up the particle.

Taking data

It is not worth working at voltages much below 100 volts. Only highly charged particles can be balanced in these small fields, and we are interested in obtaining the smallest charge possible.

Set the potential difference between the plates to about 100 volts. Turn the switch up and down a few times so that the more quickly moving particles (those with greater charge) are swept out of the field of view. Any particles that remain have low charges. If no particles remain, squeeze in some more and look again for some with small charge.

When you have isolated one of these particles carrying a low charge, adjust the voltage carefully until the particle hangs motionless. Observe it for some time to make sure that it isn't moving up or down very slowly, and that the adjustment of voltage is as precise as possible.

Read the voltmeter. Then estimate the precision of the voltage setting by seeing how little the voltage needs to be changed to cause the particle to move just perceptibly. This small change in voltage is the greatest amount by which your setting of the balancing voltage can be uncertain.

A few precise readings of the balancing voltage are more useful than several less reliable values. When you have balanced a particle, make sure that the voltage setting is as precise as you can make it before you go on to another particle. The most useful range to work in is 100-150 volts, but try to find particles that can be brought to rest in the 200-250 volt range too, if the meter can be used in that range. Remember that the higher the balancing field the smaller the charge on the particle.

Treatment of results

On a balanced particle carrying a charge q, the upward electric force, Eq, and the downward gravitational force, ma_g, are equal, so

$$ma_g = Eq.$$

The field $E = V/d$, where V is the voltage between the plates (the voltmeter reading) and d is the separation of the plates.
Hence

$$q = \frac{ma_g d}{V} \qquad (1)$$

All of the quantities on the right can be measured.

You already know a_g and have a record of V for each balanced particle.

The separation of the two plates, d, is given by the manufacturer as 5.0 mm, or 5.0×10^{-3} m. You may want to check this.

The mass of the spheres, m, is worked out from a knowledge of their volume and density.

Mass = volume × density, or

$$m = \frac{4}{3}\pi r^3 \times D.$$

The diameter (careful: 2r) has been previously measured and is given on the supply bottle, and the density, D, is 1077 kg/m^3 (found by measuring a large batch of latex before it is made into little spheres).

Notice that $ma_g d$ is a constant for all measurements and need only be found once. Each value of q will be this constant $ma_g d$ times $1/V$, as Eq. (1) shows. Because balancing voltage required is greater for smaller charges, q will be proportional to $1/V$.

Tabulate your values of V and $1/V \times 10^{-2}$ in parallel vertical columns. (Multiplying all the $1/V$ values by 10^{-2} gives numbers that are simpler to handle.)

Then arrange your values of $1/V \times 10^{-2}$ in increasing order. Notice that some values occur several times. Plot a bar graph in which the vertical axis is $1/V \times 10^{-2}$ and the horizontal axis, numbered 1, 2, 3, ... etc., is the position of the value in your ordered column.

Q8 Does your bar graph suggest that all values of q are possible and that electric charge is therefore endlessly divisible, or does it come in least-sized chunks?

Q9 What is the spacing between the observed values of 1/V, and what is the difference in charge that corresponds to this difference in 1/V?

Q10 What is the smallest value of 1/V that you observed? What is the corresponding value of q?

Q11 Do your experimental results support the idea that electric charge is quantized? If so, what is your value for the quantum of charge?

EXPERIMENT 42 The Photoelectric Effect

This experiment gives you evidence about the nature of light. Specifically, you will see what happens when light falls on a photoelectric tube; then you will compare the abilities of the wave model and the particle model of light to explain what you see.

Before doing the experiment you should read Sec. 18.4 (Unit 5). and then study the apparatus in Fig. 1. The red wire on the phototube unit goes to the red (input) terminal of the amplifier.

How the apparatus works

Light that you shine through the window of the phototube falls on a half-cylinder of metal called the emitter. The light drives electrons from the emitter surface.

Along the axis of the emitter (the center of the tube) is a wire called the collector. When the collector is made a few volts positive with respect to the emitter, practically all the emitted electrons are drawn to it, and a current appears in the external circuit.

The small photoelectric current input to the amplifier controls an output current several thousand times larger. This output current is read on a microammeter.

The voltage control knob on the phototube unit allows you to vary the voltage between emitter and collector. As you turn the knob clockwise the photocurrent drops. You are making the collector more and more negative and fewer and fewer electrons get to it. Finally the photocurrent ceases altogether--all the electrons are turned back before reaching the collector. The voltage between emitter and collector that just stops all the electrons is called the "stopping voltage." Because there is some drift of the amplifier output, the most sensitive zeroing method is to alternately cover and uncover the phototube with black paper. Then turn up the collector voltage until covering and uncovering the tube has no effect on the meter reading--the exact location of the meter pointer, which may drift around a little, isn't important.

The position of the knob at the cutoff gives you a rough measure of the collector voltage. To measure it more precisely, connect a voltmeter as shown in Fig. 2, on the next page.

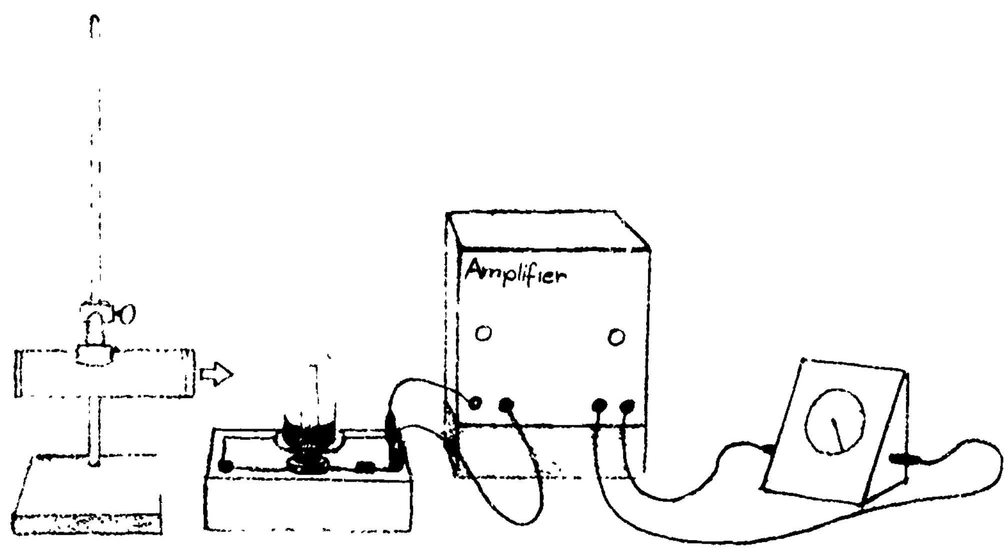


Fig. 1

In the experiment you measure stopping voltages as light of various frequencies falls on the phototube. The filters select frequencies from the mercury spectrum emitted by a fluorescent lamp or mercury lamp.

Useful frequencies of the mercury spectrum lines are:

yellow	5.2×10^{14}/sec
green	5.5×10^{14}/sec
blue	6.9×10^{14}/sec
violet	7.3×10^{14}/sec
(ultraviolet	8.2×10^{14}/sec)

You can use a hand spectroscope to find the highest frequency line passed by each filter.

Doing the experiment

The first part of the experiment is qualitative.

(1) To see how the kinetic energy of photoelectrons depends on the frequency of incident light, measure the stopping voltage with various filters over the window.

The Unit 5 text (Sec. 18.4) explains that the maximum kinetic energy of the photoelectrons is Vq_e, where V is the stopping voltage and $q_e = 1.60 \times 10^{-19}$ coulombs, the charge on an electron.

Q1 How does the stopping voltage change as the light is changed from yellow through blue or ultraviolet?

(2) To see how the current in the phototube depends on the intensity of incident light, vary the distance of the light source.

Q2 Does the number of photoelectrons emitted from the sensitive surface vary with light intensity--i.e., does the output current of the amplifier vary with the intensity of the light?

Q3 Does the kinetic energy of the photoelectrons depend on intensity--i.e., does the stopping voltage change?

(3) To see if there is time delay between light falling on the emitter and the emission of photoelectrons, cover the phototube and then quickly remove the cover.

Q4 Can you detect any time delay between the moment that light hits the phototube and the moment that the detector signals the passage of photoelectrons through the phototube?

In the second part of the experiment you make more precise measurements of stopping voltage. To do this, adjust the voltage control knob to the cutoff (stopping voltage) position and then measure V with a voltmeter (Fig. 2).

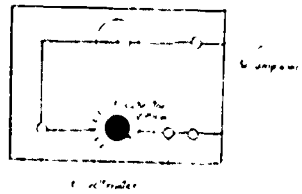


Fig. 2

Connect the voltmeter only after the cut-off adjustment is made so that the voltmeter leads will not pick up any ac voltage (induced from other conducting wires in the room) and contribute it as hum in the earphone.

Measure the stopping voltage, V, for three or four different light frequencies, and plot the data on a graph.

Along the vertical axis plot electron energy, Vq_e. (When the stopping voltage V is in volts, and q_e is in coulombs, Vq_e will be energy, in joules.)

Along the horizontal axis plot frequency of light f.

Discussion

As suggested in the opening paragraph, we are interested in comparing the wave model of light and the particle model. Consider, then, how these models explain your observations.

Q5 If light striking your phototube acts as <u>waves</u>—

a) Can you explain why the stopping voltage should depend on the frequency of light?

b) Why would you expect the stopping voltage to depend on the intensity of the light?

c) Would you expect there to be a delay between the time that light first strikes the emitter and the emission of photoelectrons? Would it matter if the intensity of light were very low?

Q6 If light is acting as a stream of <u>particles</u>, what would be the answer to each of these questions?

If you went on to draw the graph in the second part of the experiment, you should be prepared to interpret it. Remember that Einstein predicted its form (in 1905) and by experiments similar to yours, Millikan verified Einstein's prediction (in 1916).

Einstein's photoelectric equation (Unit 5 text, Sec. 18.4) describes the energy of the most energetic photoelectrons (the last ones to be stopped as the voltage is increased), as

$$\frac{1}{2}mv^2_{max} = Vq_e = hf - W.$$

This equation has the form

$$y = kx - c.$$

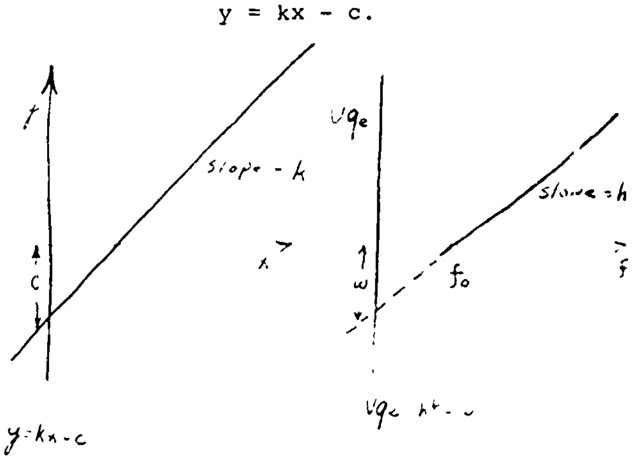


Fig. 3

In this equation $-c$ is a constant, the value of y at the point where the straight line cuts the vertical axis, and k is another constant, namely the slope of the line. Therefore, the slope of a graph of Vq_e against f should be h.

Q7 What is the value of the slope of your graph?

Q8 How well does it compare with the value of Planck's constant, $h = 6.6 \times 10^{-34}$ joule-sec?

With this equipment, the slope is unlikely to agree with the accepted value of h (6.6×10^{-34} joule-sec) more closely than an order of magnitude. Perhaps you can give a few reasons why your agreement cannot be more than approximate.

Q9 On your graph what is the threshold frequency, f_0? This is the lowest frequency at which any electrons are emitted from the cathode surface. At this frequency $\frac{1}{2}mv^2_{max} = 0$ and $hf_0 = W$, where W is the "work function." Your experimentally obtained value of W is not likely to be the same as that found for very clean cathode surfaces, more carefully filtered light, etc. The important thing to notice here is that there <u>is</u> a value of W, indicating that there is a minimum energy needed to release photoelectrons from the emitter.

Einstein's equation was derived from the assumption of a particle (photon) model of light.

Q10 If your results do not fully agree with Einstein's equation, does this mean that your experiment supports the wave theory?

ACTIVITY Writings by and about Einstein

In addition to his scientific works, Einstein wrote many essays on other areas of life which are easy to read, perceptive, and still very current. The chapter titles from Out of My Later Years (Philosophical Library, N.Y. 1950) indicate the scope of these essays: Convictions and Beliefs, Science, Public Affairs, Science and Life, Personalities, My People. This book includes his writings from 1934 to 1950. The World As I See It includes material from 1922 to 1934. Albert Einstein: Philosopher-Scientist, Vol. I (Harper Torchbook, 1959) contains Einstein's autobiographical notes, left-hand pages in German and right-hand pages in English, and essays by twelve physicist contemporaries of Einstein's about various aspects of his work. See also the three articles, "Einstein," "Outside and Inside the Elevator," and "Einstein and Some Civilized Discontents" in the Unit 5 Project Physics Reader.

ACTIVITY Measuring q/m for the electron

With the help of a "tuning eye" tube such as you may have seen in radio sets, you can measure the charge-to-mass ratio of the electron in a way that is very close to J.J. Thomson's original method.

Complete instructions are in the PSSC Physics Laboratory Guide, Second Edition, D.C. Heath and Company, 1965, Experiment IV-12, The Mass of the Electron, pp. 79-81.

When Thomson made his earliest measurements of this kind, he did not of course obtain the electron mass but rather q_e/m. To compute the mass separately, you need to know q_e, which was not known accurately until Millikan measured it.

ACTIVITY Cathode rays in a Crookes' tube

Use a Crookes' tube to demonstrate to the class the deflection of cathode rays in magnetic fields. You can also show how a magnet focuses cathode rays: bring one pole of a strong bar magnet toward the shadow of the cross-shaped obstacle on the end of the tube, as shown. Watch what happens to the shadow as the magnet gets closer and closer to it. What happens when you switch the poles of the magnet? What do you think would happen if you had a stronger magnet?

Can you demonstrate deflection by an electric field? For any given voltage supply, how can you produce the greatest possible electric field? One way is to bring your electrodes close together, but the size of the Crookes tube sets a limit on this procedure. Another way is to use sharply pointed electrodes, but sharp points tend to spark—just because they produce high electric fields.

You can keep sparks from interfering with your observations by reducing the pressure in the tube until there is too little gas present to provide an ionized path for the sparks to follow. This is how Thomson first solved the problem in 1897. If your vacuum pump is good, try it. Pump the electron-beam tube you made in experiment 37 to a good enough vacuum so that you can observe electric deflection without sparking. (This will require rather high voltages—be careful.) Then slowly let in air until the effect is no longer visible. At this higher pressure, can you still obtain magnetic deflections?

If you have an electrostatic generator, such as a small Van de Graaff or a Wimshurst machine, try deflecting the rays using parallel plates across the generator.

ACTIVITY X-rays from a Crookes' tube

A Crookes' tube having a metal barrier inside it for demonstrating that cathode rays travel in straight lines may be available in your classroom. In use the tube is excited by a Tesla coil or induction coil.

Fig. 1

To demonstrate that x rays penetrate materials which stop visible light, place a sheet of 4 x 5 3000 speed Polaroid film, still in its protective paper jacket, in contact with the end of the Crookes' tube. (A film pack cannot be used unless you are willing to sacrifice the entire pack. Any other photographic film in a light-tight paper envelope could be substituted.) Support the film on books or the table so that it doesn't move during the exposure. Figure 1 was a 1-minute exposure using a hand-held Tesla coil to excite the Crookes' tube.

ACTIVITY Lighting a light bulb with a match photoelectrically

Here is a trick that you can challenge your friends with. It illustrates one of the many amusing and useful applications of the photoelectric effect in real life.

Equipment

1P39 photocell

6-volt, 15-watt light bulb (light source from the Millikan apparatus)

6-volt, 2.5-amp power supply (or dry cell)

amplifier

transistor switch

The photocell is the same one as is used in Experiment 42, The Photoelectric Effect. The light source from the Millikan apparatus is suitable.

Position the photocell and light bulb as close to each other as possible, leaving just enough room to insert a lighted match between them (3/4 inch or so). Assemble the rest of the equipment and wire it as indicated in Fig. 1.
Turn the GAIN up all the way. With the

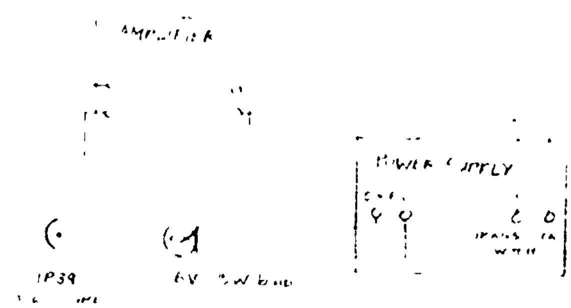


Fig. 1

DC OFFSET near zero and the DC-AC switch set at DC, turn on the amplifier. Now turn the DC OFFSET up until the light bulb goes on, then turn it down very carefully until the bulb is just not quite lit.

When the circuit is adjusted properly, a lighted match inserted between the bulb and the photocell activates the photocell, turning on the current through the transistor switch to the bulb. Once the bulb is lit, it keeps the photocell activated by its own light; you can remove the match and the bulb will stay lit.

When you are demonstrating this effect, tell your audience that the bulb is really a candle and that it shouldn't surprise them that you can light it with a match. And of course one way to put out a candle is to moisten your fingers and pinch out the wick. When your fingers pass between the bulb and the photocell, the bulb turns off, although the filament may glow a little, just as the wick of a freshly snuffed candle does. You can also make a "candle-snuffer" from a little cone of any reasonably opaque material and use this instead of your fingers. Or you can "blow out" the bulb: it will go out obediently if you take care to remove it from in front of the photocell as you blow it out.

EXPERIMENT 43 Spectroscopy

Spectra are immensely useful. Elements and compounds can be identified by examining their spectra. Scientists learn about the structure of atoms and molecules and determine the composition of distant stars and nebulae by studying their spectra.

You are about to observe the spectra of a variety of sources to see how they differ and to learn how to measure wavelengths of the light emitted. You will be able to measure the wavelengths of the spectrum lines of hydrogen and to relate these wavelengths to the structure of the hydrogen atom.

Materials can be made to give off light (can be "excited") in several different ways: by heating in a flame, by an electric spark between electrodes made of the material, or by an electric current through a gas at low pressure.

The light emitted can be dispersed into a spectrum by either a prism or a diffraction grating.

In this experiment you will use a diffraction grating to examine light from various sources. A diffraction grating consists of many very fine parallel grooves on a piece of glass or plastic. The grooves can be seen under a 400-power microscope.

In Experiment 32 (Young's experiment) you saw how two narrow slits spread light of different wavelengths through different angles, and you used the double slit to make approximate measurements of the wavelengths of light of different colors. The distance between the two slits was about 0.2 mm. The distance between the lines in a diffraction grating is about 0.002 mm. And there may be about 10,000 grooves instead of just two. Because there are more lines and they are closer together, the grating separates (disperses) the different wavelengths much more, and can be used to make accurate measurements of wavelength.

Observing spectra

You can observe diffraction when you look at light that is reflected from a phonograph record. Hold the record (diffraction grating) so that light from a distance source is almost parallel to the record's surface (Fig. 1). You will see that the grooved surface disperses light into a spectrum.

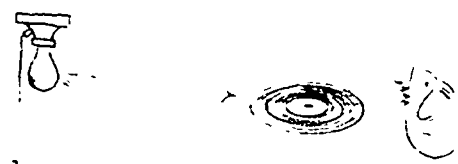


Fig. 1

Use a diffraction grating to see spectra simply by holding the grating close to your eye with the lines of the grating parallel to a light source. Better yet, arrange a slit about 25 cm in front of the grating, as in a pocket spectroscope.

Look through the pocket spectroscope at a fluorescent light, at an ordinary (incandescent) light bulb, at mercury-vapor and sodium vapor street lamps, at neon signs, at light from the sky (but don't look directly at the sun) and at a flame into which various compounds are introduced (such as salts of sodium, potassium, strontium, barium and calcium).

You should now be able to answer some questions about spectra.

Q1 Which colors are bent (diffracted) most and which least by the grating? Are the long wavelengths diffracted more than the short, or vice-versa?

Q2 What different kinds of spectra can you describe?

Make a table showing the type of spectrum produced by each of the light sources you observed.

Photographing the spectrum

You can make measurements of the wavelengths of spectral lines from a photograph of the spectrum.

An advantage of a photograph is that it reveals a greater range of wavelengths than can be seen by the human eye.

When you hold the grating up to your eye, the lens of your eye focusses the diffracted rays to form a series of colored images on the retina. If you put the grating in front of the camera lens focussed on the source, the lens will produce sharp images on the film.

The spectrum of hydrogen is a particularly interesting one to measure because hydrogen is the simplest atom and its spectrum is fairly easily related to a model of its structure. In this experiment atomic hydrogen gas in a glass tube is excited by an electric current.

Set up a meter stick just behind the tube (Fig. 2). This is a scale against which to observe and measure the position of the spectrum lines.

Look through the grating at the glowing tube to locate the positions of the visible spectral lines against the meter stick.

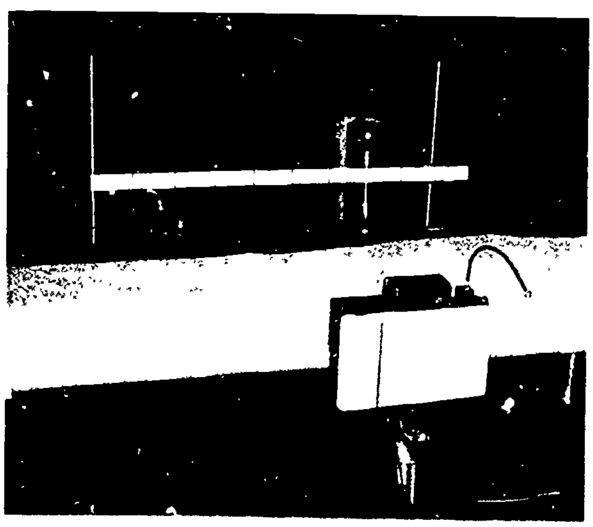


Fig. 2

Then fasten the grating over the camera lens and set up the camera with its lens in the same position your eye was.

Remember that the grating lines must be parallel to the source.

Now take a photograph that shows both the scale on the meter stick and the spectral lines. You may be able to take a single exposure for both, or you may have to make a double exposure—first the spectrum, and then, with more light in the room, the scale. It depends on the amount of light in the room. Consult your instructor.

Analyzing the spectrum

Count the number of spectral lines on the photograph. Use a magnifying eyepiece to help pick out the faint ones.

Q3 Are there more lines than you can see when you hold the grating up to your eye? If so, are the new lines in the visible part of the spectrum (between red and violet) or in the ultraviolet or infrared?

The angle θ through which light is bent by a grating depends on the wavelength λ of the light and the distance d between lines on the grating. The formula is a simple one:

$$\lambda = d \sin \theta.$$

To find θ you need to find, as shown in Figure 3, $\tan \theta = x/\ell$; x is the distance of the spectral line along the meter stick from the source, and ℓ is the distance from the source to the grating. Use a magnifying glass to read x

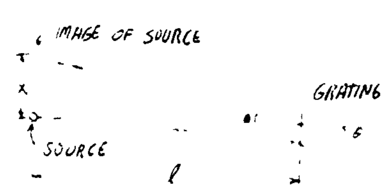


Fig. 3

from your photograph, then calculate $\tan \theta$. Then look up the corresponding values of θ and $\sin \theta$ in tables.

To find d remember that the grating space is probably given as lines per inch. You must convert this to the distance between lines in meters. One inch is 2.54×10^{-2} meters, so if there are 13,400 lines per inch, then d is

$$(2.54 \times 10^{-2})/(1.34 \times 10^{-4}) = 1.89 \times 10^{-6} \text{ meters.}$$

Calculate the values of λ for the various spectral lines you have measured.

Q4 How many of them are visible to the eye?

Q5 What would you say is the shortest wavelength to which your eye is sensitive?

Q6 What is the shortest wavelength that you can measure on the photograph?

Compare your values for the wavelengths with those given in the text (Unit 5, Table 19.1 on page 69), or the more complete list given for instance in the <u>Handbook of Chemistry and Physics</u>. The differences between your values and the published ones should be less than the experimental uncertainty of your measurements. Are they?

This is not all that you can do with the results of this experiment.

You could work out a value for the Rydberg constant for hydrogen. (See Unit 5, text page 69 for the formula that defines R_H.)

More interesting perhaps is to calculate some of the energy levels for the excited hydrogen atom. Use Planck's constant (see Unit 5, Sec. 18.5 and Experiment 42 on the photoelectric effect) to calculate the energy of photons of various wavelengths, $E = hf = hc/\lambda$, emitted when hydrogen atoms change from one state to another. The energy of the emitted photon is the difference in energy between the initial and final states of the atom.

Make the assumption (which is correct) that for all lines of the series you have observed (Balmer series) the final energy state is the same. The energies that you have calculated represent the energy of various excited states above this final level.

Draw an energy level diagram something like the one shown here (Fig. 4). Show on it the energy of the photon emitted in transition from each of the excited states to the final state.

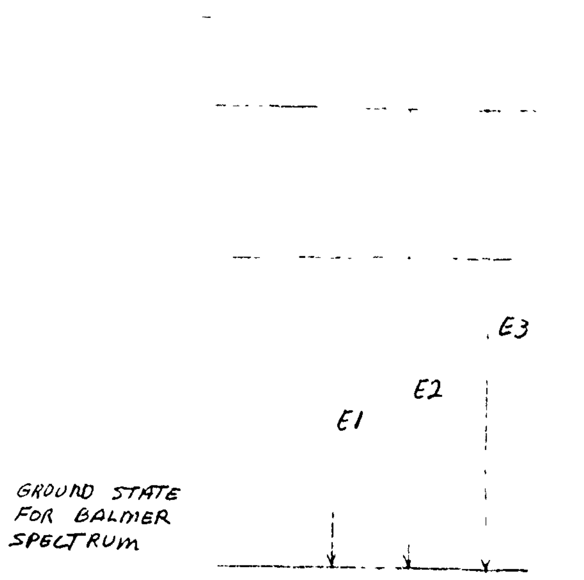


Fig. 4

Q7 How much energy does an excited hydrogen atom lose when it emits red light?

ACTIVITY **Scientists on stamps**

As shown above, scientists are pictured on the stamps of many countries, often being honored by other than their homeland. You may want to visit a stamp shop and assemble a display for your classroom.

See also "Scientists on Stamps," in the Unit 4 Student Handbook.

ACTIVITY **Measuring a quantum effect: ionization**

With an inexpensive thyratron 885 tube, you can demonstrate an effect that is closely related to the famous Franck-Hertz effect.

Theory

According to the Rutherford-Bohr model, an atom can absorb and emit energy only in certain amounts. If an atom is exposed to larger quanta of energy, it will at first be very finicky, accepting only those quanta that correspond to permitted "jumps" between states. This is the Franck-Hertz effect.

But if you keep increasing the energy, you will finally get on one which is large enough to separate an electron entirely from its atom—that is, enough to ionize the atom. This energy is called the ionization energy.

Now imagine a stream of electrons being accelerated by an electric field through a region of space filled with argon atoms. This is the situation in a thyratron 884 tube with its grid and

Activities

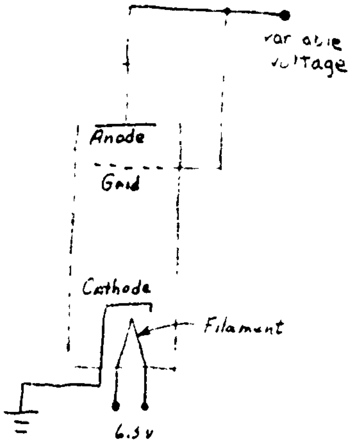


Fig. 1 The thyratron tube

anode both connected to a scurce of variable voltage, as shown schematically in Fig. 1. As long as the energy is below that needed for "jumps", the atoms will not accept any energy. As you increase the accelerating voltage, the electrons become energetic enough to excite the atoms, as in the Franck-Hertz effect. However, our equipment is not sensitive enough to detect the resulting small energy absorptions. So nothing much seems to happen: the electron current from cathode to anode appears to increase quite linearly with the voltage, as you would expect—until the electrons get up to the ionization energy of argon. This happens at the ionization potential V_i, which is related to the ionization energy E_i and to the charge q_e on the electron as follows:

$$E_i = q_e V_i \qquad (1)$$

As soon as electrons begin to ionize argon atoms, the current increases sharply. The argon is now in a different state, called an ionized state, in which it conducts electric current much more easily than before; this sudden decrease in electrical resistance makes the thyratron tube useful as an "electronic switch" in such devices as stroboscopes. A similar process changes the air so that it can conduct lightning. As argon ions recapture electrons, they emit photons of ultraviolet and of visible violet light. This violet glow is evidence that the argon is in an excited state.

For theoretical purposes, the important point is that ionization takes place in any gas at a particular energy that is characteristic of that gas. This is an easily observed evidence of one special case of Bohr's postulated discrete energy states.

Equipment

thyratron 884 tube

octal socket to hold the tube (not essential but convenient)

voltmeter (0-30 volts dc)

ammeter (0-100 milliamperes)

potentiometer (10,000 ohms, 2 watts or larger) (OR variable transformer, 0-120 volts ac)

power supply, capable of delivering 50-60 ma at 200 volts dc.

Connect the apparatus as shown in Fig. 2. If you use a

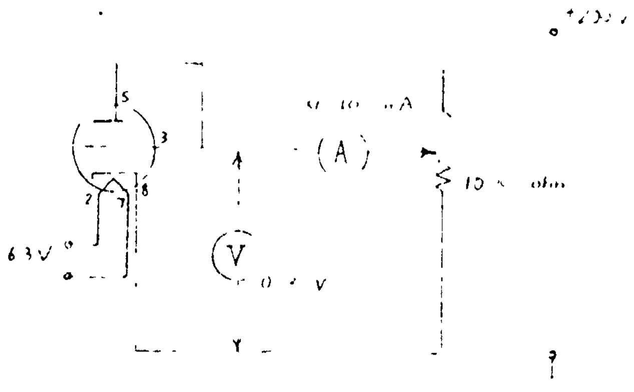


Fig. 2 Schematic diagram

variable transformer to run the power supply (instead of controlling its output with a potentiometer), you will need a separate 6.3-volt supply for the filament of the tube.

Procedure

With the potentiometer set for the lowest available anode voltage, turn on the power and wait a few seconds for the filament to heat. Now increase the voltage by small steps. At each new voltage, call out to your partner the voltmeter reading. Pause only long enough to permit your partner to read the ammeter and to note both readings in your data table. Take data as rapidly as accuracy permits: your potentiometer will heat up quickly, especially at high currents. If it gets too hot to touch, turn the power off and wait for it to cool before beginning again.

Watch for the onset of the violet glow. Note in your data table the voltage at which you first observe the glow, and then note what happens to it at higher voltages.

Plot current versus voltage, and mark the point on your graph where the glow first appeared. From your graph, determine the first ionization potential of argon. Compare your experimental value with published values, such as the one in the Handbook of Chemistry and Physics.

Use $E_i = q_e V_i$ to compute the energy (in electron volts and in joules) that an electron must have in order to ionize and argon atom.

ACTIVITY Modeling atoms with magnets

Here is one easy way to demonstrate some of the important differences between the Thomson "pudding" atom model and the Rutherford nuclear model.

Equipment

A dry ripple tank

tiny plastic beads to reduce friction on the glass surface of the ripple tank

one large, flat, cylindrical magnet about two inches in diameter (to represent an alpha particle)

five or six small flat disc magnets about an inch in diameter (to represent the deflecting charges within the atom)

To show how alpha particles would be expected to behave in collisions with a Thomson atom, represent the spread-out "pudding" of positive charge by a roughly circular arrangement of the small magnets, spaced four or five inches apart, under the center of the tray, as shown in Fig. 1.

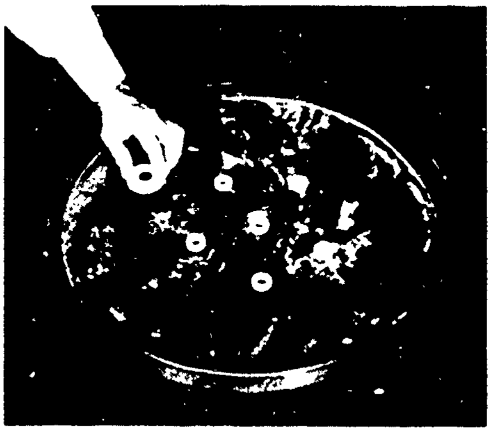


Fig. 1 The arrangement of the magnets for a "Thomson Atom".

Use tape or putty to fasten the magnets to the underside of the glass. Put the large magnet (representing the alpha particle) down on top of the glass so that it is repelled by the small magnets. Now fire (push) it from the edge of the glass toward the "atom." As long as it has enough momentum to reach the other side, its deflection by the small magnets under the tray will be quite small—never never more than a few degrees.

For the Rutherford model, on the other hand, gather all the small magnets into a vertical stack under the center of the tray, as shown in Fig. 2. Turn the stack

(continued on page 36)

Activities

Chemi-Crostic

After each definition is a dash for each letter in the word defined Write each word on the appropriate dashes and write each letter in the square with the corresponding number in the diagram When the squares are filled, the diagram will give a quotation, reading from left to right, from a well known scientist Black squares indicate the ends of words and if there is no black square at the right side of the diagram, the word continues on the next line When all the words have been supplied for the definitions, the first letter of each word defined, reading from top to bottom (definitions **A** to **U**), will spell the name of the scientist and the topic of the quotation If a word can be completed in the diagram without using the definitions, the letters may be transferred to the definitions by using the number and letter of the square in which the letter appears For instance, if numbers 137P, 138**R**, and 139**H** in the puzzle read A D, the letter N might be supplied for the missing letter to complete the word AND The letter N was in square number 138**R** Therefore, going back to the definition numbered **R**, the letter N should be filled into the line mark d 138 in that definition The complete quotation for the crostic may be found in the *Journal of Chemical Education* [39, p 288, line 15 (1962)]. *This puzzle was contributed by Mary Ellen Schaff, University of Wisconsin, Milwaukee, Wis* (*Solution will appear next month*)

1 O	2 R		3 H	4 J	5 E		6 B	7 F	8 O	9 G	10 F		11 S	12 O
13 H		14 S	15 C	16 F	17 M		18 E	19 B	20 F	21 Q	22 O	23 J	24 B	25 D
26 N	27 A		28 G	29 N	30 R	31 E	32 U		33 H	34 J	35 A	36 J		37 S
38 E	39 D		40 P	41 Q	42 Q	43 E		44 E	45 H	46 L	47 O	48 M	49 F	50 T
51 K		52 Q	53 T		54 H	55 D		56 F	57 K		58 U	59 T		60 H
61 N	62 P	63 M		64 F	65 L		66 H	67 M	68 L		69 U	70 H	71 E	72 H
73 G	74 E		75 A	76 U		77 Q	78 A	79 F	80 I	81 B	82 D	83 R	84 T	85 F
86 O		87 K	88 J		89 R	90 H		91 J	92 E	93 L		94 C	95 P	96 A
97 C	98 I		99 M		100 A	101 H	102 G	103 A	104 I	105 U	106 P		107 Q	108 C
109 R	110 H		111 Q	112 G	113 S	114 H	115 C		116 D	117 O		118 D		119 E
120 U	121 L	122 M	123 N		124 F	125 P		126 B	127 G	128 H	129 I	130 B	131 A	
132 J	133 K	134 O	135 F	136 F		137 P	138 R	139 H		140 K	141 C		142 A	143 R
144 A	145 E		146 F	147 D	148 M	149 U		150 I	151 E	152 R		153 O	154 I	155 D
	156 J	157 E	158 B											

Reprinted from Chemistry, November, 1966.

A. Scattering of light by molecules resulting in a shift in wavelength (two words)

96 35 144 75 78 131 100 90 27 142 103

B. Marked by disturbance

158 19 6 130 24 81 126

C. Polymerized tetrafluoroethylene

141 97 94 115 15 108

D. Has subsided (two words)

12 147 39 116 25 118 155 55 82

E. Optical isomers

145 151 38 31 74 18 92 71 157 43 119 44 5

F An acid important in protein synthesis (two words)

136 56 146 124 16 135 49 7 79 85 10 64 20

G. Object irrationally reverenced

102 28 9 127 73 112

H. Nobel Prize winner in chemistry, 1909 (last name first)

72 128 33 3 45 70 139 66 101 60 110 13 114 54

I. Elevated

80 150 154 129 104 98

J. Lack of sympathy

23 156 88 132 4 36 34 91

K. A river nymph

57 87 140 133 51

L. Emotionally disturbed

93 46 68 121 65

M. The order of marine mammalia containing whales

148 63 17 67 122 48 99

N. Unexploded (of a shell)

26 61 29 123

O. A plant which obtains nutrients from air (as spelled here, sixth letter is "i")

22 47 1 134 153 8 117 86

P. Branch of geometry (Leonhard Euler)

137 62 125 95 106 40

Q. To pay a second call

21 42 41 107 111 77 52

R. Series of radioactive elements

143 109 2 83 138 89 152 30

S. The objective case of they

11 37 113 14

T. Heed a call

53 84 50 59

U. Error

58 120 76 32 69 149 105

Reprinted from October 1966 Chemistry. (Answer appears at end of activities for Chapter 20.)

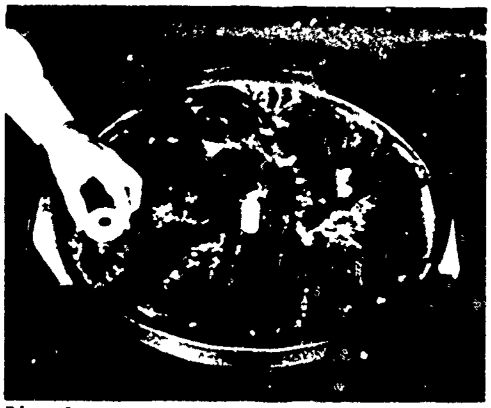
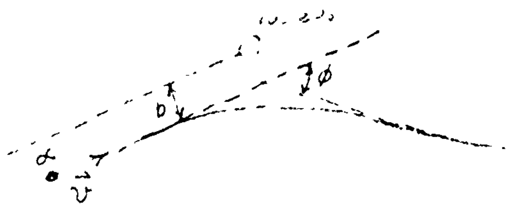


Fig. 2. The arrangement of the magnets for a "Rutherford atom."

so that it repels "alpha particles" as before. This "nucleus of positive charge" now has a much greater effect on the path of the "alpha particle."

This magnet analogue is good enough so that you can do some quantitative work with the scattering relationships that Rutherford investigated (see Sec. 19.3 and Film Loop 48, Rutherford Scattering). Try varying the sizes of the magnets. Devise a launcher so that you can control the velocity of your projectile magnets and the distance of closest approach.



1. Hold the projectile velocity v constant and vary the distance b (see Fig. 3); then plot the scattering angle ϕ versus b.

2. Hold b constant and vary the speed of the projectile, then plot ϕ versus v.

3. Try scattering hard, nonmagnetized discs off each other. Plot ϕ versus b and ϕ versus v as before. Contrast the two kinds of scattering-angle distributions.

ACTIVITY Cigar box atoms

Place two or three different objects, such as a battery, a small block of wood, a bar magnet or a ball bearing, in a cigar or shoebox. Seal the box, and have one of your fellow students try to tell you as much about the contents of your "atom" as possible, without opening the box. For example, sizes might be determined by tilting the box, relative masses by balancing the box on a support, or whether or not the "atom" is magnetic by checking with a compass.

The object of all this is to get a feeling for what you can or cannot infer about the structure of an atom purely on the basis of secondary evidence. It may help you to write a report on your investigation in the form you may have used for writing a proof in plane geometry, i.e., the property of the atom in one column and your reason for asserting that the property is present in the other column. Evidence: "a compass is deflected when brought near. Conclusion: my atom is magnetic."

ACTIVITY Another simulation of the Rutherford atom

A hard rubber "potential-energy hill" is available from Stark Electronics Instruments, Ltd., Box 670, Ajax, Ontario, Canada. When you roll steel balls onto this hill, they are deflected in somewhat the same way as alpha particles are deflected away from a nucleus. The potential-energy hill is very good for quantitative work such as was suggested for the magnet analogue above.

FILM LOOP 47 Thomson Model of the Atom

Before the development of the Bohr theory, a popular model for atomic structure was the "raisin pudding" model of J. J. Thomson. According to this model, the atom was supposed to be a uniform sphere of positive charge in which were embedded small negative "corpuscles" (electrons). Under certain conditions the electrons could be detached and observed separately, as in Thomson's historic experiment to measure the charge-mass ratio.

The Thomson model did not satisfactorily explain the stability of the electrons and especially their arrangement in "rings," as suggested by the periodic table of the elements. In 1904 Thomson performed experiments which to him showed the <u>possibility</u> of a ring structure within the broad outline of the raisin-pudding model. Thomson also made mathematical calculations of the various arrangements of electrons in his model.

In the Thomson model of the atom, the cloud of positive charge created an electric field directed along radii, strongest at the surface of the sphere of charge and decreasing to zero at the center. You are familiar with a gravitational example of such a field. The earth's downward gravitational field is strongest at the surface and it decreases uniformly toward the center of the earth.

For his model-of-a-model Thomson used still another type of field—a magnetic field caused by a strong electromagnet above a tub of water. Here, too, the field is radial as shown by the pattern of iron filings sprinkled on the glass bottom of the tub. Thomson used vertical magnetized steel needles to represent the electrons; these were stuck through corks and floated on the surface of the water. The needles were oriented with like poles pointing upward; their mutual repulsion

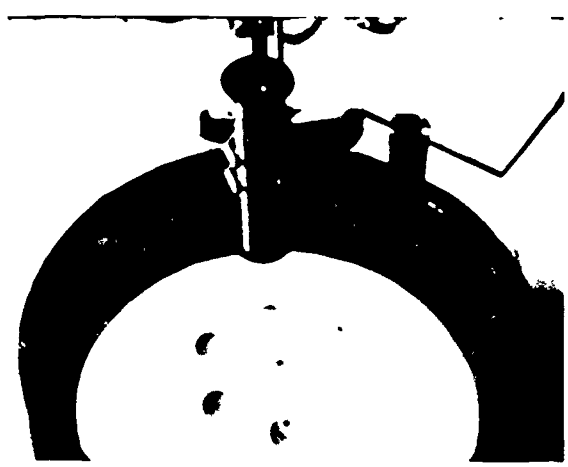


Fig. 1

tended to cause the magnets to spread apart. The outward repulsion was counteracted by the radial magnetic field directed inward toward the center. When the floating magnets were placed in the tub of water, they came to equilibrium configurations under the combined action of all the forces. Thomson saw in this experiment a partial verification of his calculation of how electrons (raisins) might come to equilibrium in the raisin-pudding model of the atom.

In the film the floating magnets are 3.8 cm long, supported by ping pong balls. Equilibrium configurations are shown for various numbers of balls, from 1 to 12. Perhaps you can interpret the patterns in terms of rings, as did Thomson (Fig. 2 on the next page).

Thomson was unable to make an exact correlation with the facts of chemistry. For example, he knew that the eleventh electron is easily removed (corresponding to sodium, the eleventh atom of the periodic table), yet his floating magnet model failed to show this. Instead, the patterns for 10, 11 and 12 floating magnets are rather similar.

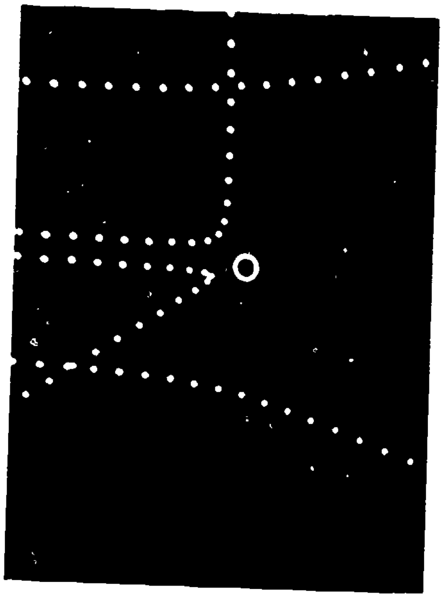


Fig. 1

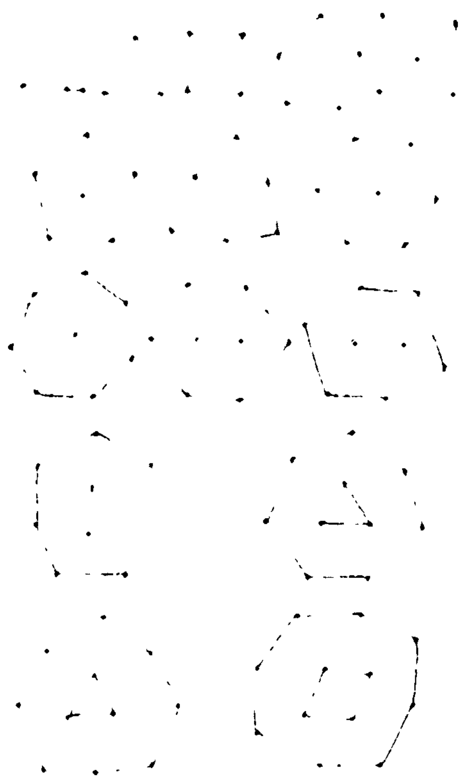


Fig. 2

Thomson's work with this apparatus illustrates how physical theories may be tested with the aid of analogies. He was disappointed by the failure of the model to account for the details of atomic structure. A few years later the Rutherford model of a nuclear atom made the Thomson model obsolete, but in its day the Thomson model received some support from experiments such as those shown in the film.

FILM LOOP 48 Rutherford Scattering

A computer program was used to make this film, which shows the scattering of alpha particles by a nucleus in a solid-like gold foil (Fig. 1). Notice that particles which are aimed to pass close to the nucleus are scattered through large angles. Other particles which are not aimed so close to the nucleus are deflected through smaller angles. The interaction between the alpha particle and the nucleus is the electrostatic force of repulsion between two positively charged bodies. According to Coulcmb's law, this force varies inversely as the square of the distance between the alpha particle and the nucleus.

The program used in the computer was a slight modification of that used in the film loop "Program Orbit." The only difference is that the operator selected an inverse-square law of repulsion instead of a law of attraction such as that of gravity. The output of the computer was displayed on a cathode-ray tube. Points are shown at equal time intervals. Careful measurements would show that the law of areas is valid for the motion of the alpha particles. Why would you expect this to be true?

The scattering is shown only for particles which are in the near vicinity of a nucleus. Drawn to scale, the nearest adjacent nucleus would be about 500 feet above the nucleus shown (if the image from your projector is 1 foot high) Any alpha particles moving across this large area between nuclei would move toward the right with no observable deflection.

We use the computer to tell us what the result will be if we shoot particles at a nucleus. Remember that the computer program doesn't "know" about Rutherford scattering. The operator has "built in" only Newton's laws of motion and the physical force law (inverse-square repulsive force). It would be easy enough to change the program to test the effect of some other force law, for example, $F = K/r^{2.1}$ instead of $F = K/r^2$. The scattering would be computed and displayed on the CRT; the angle of each scattering deflection would depend on the distance of closest approach, but differently than for the inverse-square force law.

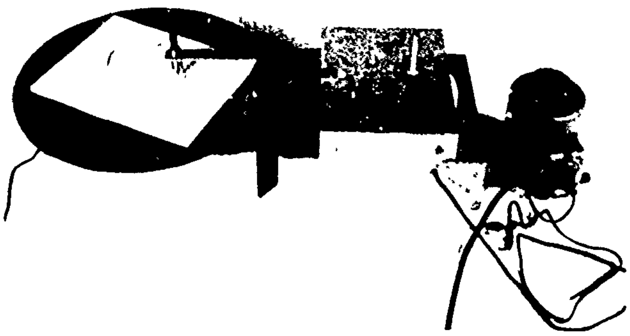
Working backward from the observed scattering data, Rutherford deduced that the inverse-square Coulomb force law is correct for all motions taking place at distances greater than about 10^{-14} m from the scattering center, but he found deviations from Coulomb's law for closer distances. In this way a new type of force was discovered, called nuclear force. Rutherford's scattering experiment showed the size of the nucleus to be about 10^{-14} m, which is about 1/10,000 the distance between the nuclei in solid bodies.

ACTIVITY Standing waves on a band-saw blade

Standing waves on a ring can be shown by shaking a band-saw blade with your hand. To protect your hand wrap tape around the blade for about six inches. Then gently shake the blade up and down until you have a feeling for the lowest vibration rate which produces reinforcement of the vibration. Then double the rate of shaking, and continue increasing the rate of shaking, watching for standing waves at all times. You should be able to maintain five or six nodes.

ACTIVITY Turntable oscillator patterns resembling de Broglie waves

If you set up two turntable oscillators and a Variac as shown in Fig. 1, you can draw pictures like those shown in Fig. 20.4 of your Unit 5 text resembling de Broglie waves.



Place a paper disc on the turntable. Set both turntables to their lowest speeds. Before starting to draw, check the back-and-forth motion of the second turntable to be sure the pen stays on the paper. Turn both turntables on and use the Variac as a fine speed control on the second turntable. Your goal is to get the pen to follow exactly the same path each time the paper disc goes around. Try higher frequencies of back-and-forth motion to get more wavelengths around the circle. For each stationary pattern that you get, check whether the back-and-forth frequency is an integral multiple of the circular frequency.

ACTIVITY Standing waves in a wire ring

With the apparatus described below, you can set up circular standing waves that resemble vaguely the de Broglie wave models of certain electron orbits.

Equipment

wire ring
Project Physics close up power supply
(with transistor switch)
strong permanent magnet

Set the oscillator RANGE switch to 5-50 cyc/sec. Connect the square-wave oscillator output to the TRANSISTOR SWITCH input of the power supply.

The output current of the oscillator is much too small to set up visible standing waves in the wire ring. However, the oscillator current can operate the transistor switch to control a much larger current from the power supply.

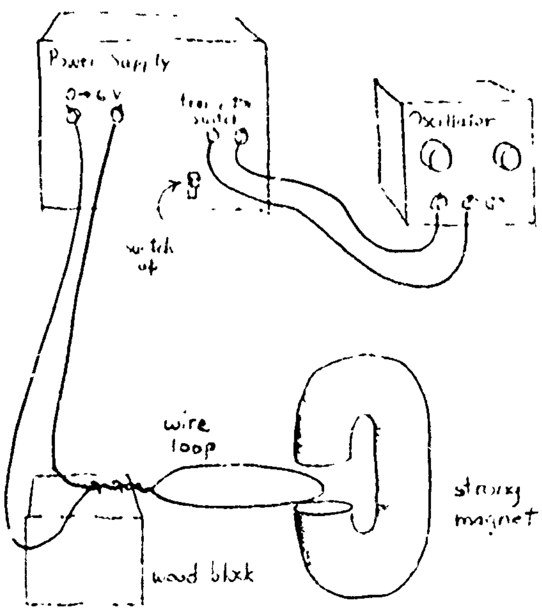


Fig. 1

The wire ring must be made of copper or any non-magnetic metal. Insulated copper magnet wire works well: twist the ends together and support the ring at the twisted portion by means of a binding post, Fahnestock clip, or ring-stand clamp. Remove a little insulation from each end for electrical connections.

A ring 4 to 6 inches in diameter made of 22-gauge enameled copper wire has its lowest rate of vibration at about 20 cycles/sec. Stiffer wire or a smaller ring will have higher characteristic vibrations which are more difficult to see.

Position the ring as shown, with a section of the wire passing between the poles of the magnet. When the signal current passes through the ring, the current interacts with the magnetic field, producing alternating forces which cause the wire to vibrate. In Fig. 1, the magnetic field is vertical, and the vibrations are in the plane of the ring. You can turn the magnet so that the vibrations are perpendicular to the ring.

Because the ring is clamped at one point, it can support standing waves that have any integral number of half wavelengths. In this respect they are different from waves on a free wire ring (which is more appropriate for comparison to an atom) which are restricted to integral numbers of whole wavelengths.

When you are looking for a certain mode of vibration, position the magnet between expected nodes. The first stationary state that the ring can support in its plane is the first harmonic, having two nodes: the one at the point of support and the other opposite it. In the second mode, three nodes are spaced evenly around the loop, and the best position for the magnet is directly opposite the support, as shown in Fig. 1.

You can demonstrate the various modes of vibration to the class by setting up the magnet, ring and support on the platform of an overhead projector. Be careful not to break the glass with the magnet, especially if the frame of the projector happens to be made of a magnetic material.

Project Physics film loop 47, Vibrations of a Wire, also shows this.

Answer to "Chemi - Crostic," on page 34 of this handbook.

I	T	■	W	A	S	■	Q	U	I	T	E	■	T	H
E	■	M	O	S	T	■	I	N	C	R	E	D	I	B
L	E	■	E	V	E	N	T	■	T	H	A	T	■	H
A	S	■	E	V	E	R	■	H	A	P	P	E	N	E
D	■	T	O	■	M	E	■	I	N	■	M	Y	■	L
I	F	E	■	I	T	■	W	A	S	■	A	L	M	O
S	T	■	A	S	■	I	N	C	R	E	D	I	B	L
E	■	A	S	■	I	F	■	Y	O	U	■	F	I	R
E	D	■	A	■	F	I	F	T	E	E	N	■	I	N
C	H	■	S	H	E	L	L	■	A	T	■	A	■	P
I	E	C	E	■	O	F	■	T	I	S	S	U	E	■
P	A	P	E	R	■	A	N	D	■	I	T	■	C	A
M	E	■	B	A	C	K	■	A	N	D	■	H	I	T
■	Y	O	U	■	■	■	■	■	■	■	■	■	■	■

A Scattering of light by molecules resulting in a shift in wavelength (two words) RAMAN EFFECT

B Marked by disturbance UNQUIET

C. Polymerized tetrafluoroethylene TEFLON

D. Has subsided (two words) HAS ABATED

E. Optical isomers ENANTIOMORPHS

F. An acid important in protein synthesis (two words) RIBOSE NUCLEIC

G. Object irrationally reverenced FETISH

H Nobel Prize winner in chemistry, 1909 (last name first) OSTWALD WILHELM

I. Elevated RAISED

J. Lack of sympathy DYSPATHY

K. A river nymph NAIAD

L. Emotionally disturbed UPSET

M. The order of marine mammalia containing whales CETACEA

N Unexploded (of a shell) LIVE

O A plant which obtains nutrients from air (as spelled here sixth letter is "i") EPIPHITE

P. Branch of geometry (Leonhard Euler) AFFINE

Q. To pay a second call REVISIT

R Series of radioactive elements ACTINIDE

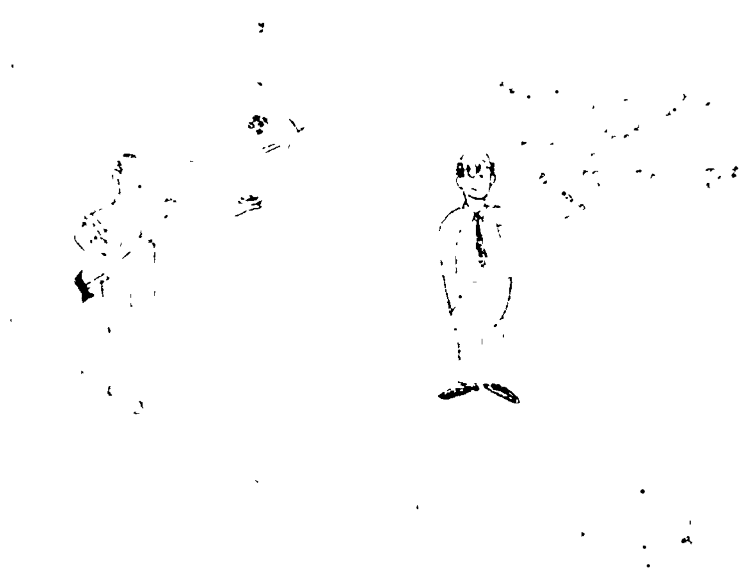
S. The objective case of they THEM

T. Heed a call OBEY

U. Error MISTAKE

The puzzle quotation, from "The Nuclear Atom" by Sir Ernest Rutherford, appeared in the *Journal of Chemical Education* (June 1962, p 288) At one time, atoms were thought to be negative electricity scattered through a sphere of positive charge However, when metals were bombarded with helium nuclei, the particles bounced back This was not in accord with theory, and Rutherford described the phenomenon as " quite the most incredible event "

Reprinted from Chemistry, November, 1966, p. 42.



IMAGES OF THE ATOM WHICH IS MORE USEFUL ?
WHICH ONE IS THE ATOM REALLY LIKE ?