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EXPERIMENTALLY ORIENTED SCIENCE EXHIBITS

MASTER

From the Lawrence Hall of Science

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EXPERIMENTALLY ORIENTED SCIENCE EXHIBITS

Designed and constructed by Lawrence Hall of Science
University of California Berkeley, California

This report written by

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Introduction

Seventeen of some fifty science exhibits already completed or presently under construction at the Lawrence Hall of Science are discussed briefly in this nontechnical report. Each exhibit is designed to stimulate interest in and facilitate learning of some of the basic fundamentals in each of several disciplines of science.

The staff, consisting of Harvey E. White, Director, Hans Weltin, Robert A. Rice, Mauri Gould, Ferdinand S. Ruth, Kenneth V. Jackman, David E. Ridgway, Jack E. Campbell, and Robert L. Tanquary, is grateful to the U. S. Atomic Energy Commission, the U. S. Office of Education, and the Sloan Foundation, whose support made it possible to do this work. Appreciation is also expressed to the Commission and especially to Janice M. Asher of the Division of Technical Information for editorial assistance in preparing this publication.

It is hoped that science museums, colleges, universities, teachers, and students will find use for these devices and will consult freely with the Lawrence Hall of Science relative to construction details and possible changes that might improve the use of these exhibits. Questions and suggestions should be directed to Dr. Harvey E. White, Director, Lawrence Hall of Science, University of California, Berkeley, California 94720.

Gamma-ray Absorption

In this exhibit the visitor examines the extent to which lead absorbs gamma rays. He observes on a meter (see Fig. 1) the intensities of gamma radiation passing through different thicknesses of lead. He may record the readings and make a plot of radiation for various thicknesses of lead.

A response box built into the unit contains a question with three multiple-choice answers. This unit can be operated only when an answer card is inserted in a slot; the machine records the answer by punching the card. When a wrong answer is chosen, an explanation is flashed on a screen. (See the section How Good Is an Exhibit? for a description of the response box.)

Text and illustrations may be added to point out that the shielding effect (absorption) is directly proportional to weight (mass) and that lead is a commonly used shielding material.

A pad in front of the unit actuates a counter when the operator steps on it; thus the number of people coming to the unit is recorded. The pad turns off the unit when the visitor leaves.

Equipment that will record the following information is available:

1. How long the viewer spent operating the exhibit.
2. Whether or not he completed the planned procedure.
3. Whether or not he obtained the correct answer.
4. How many people operated the exhibit.

PURPOSE

The purpose is given on the face of the unit in two questions:

What thickness of lead will absorb one-half of the gamma rays?

Would double this thickness of absorber reduce the radiation to zero?

EQUIPMENT

The following equipment is located behind glass, is well labeled, and is operated by knobs and buttons:

1. *A gamma source.* The source is 30 microcuries of sodium-22. It is suggested by Dr. Hans Weltin, who designed the machine, that a cobalt-60 source be used in the future.

Gamma Ray Absorption

What thickness of lead will absorb one-half of the gamma rays?

Would double this thickness of absorber reduce the radiation to zero?

Lead Absorber	None	1	2	3	4	5	6	7	8
Thickness in centimeters	0	0.4	0.6	0.8	1.0	1.2	1.3	1.5	2.5

Lead shield and radioactive source

Lead shield

Scintillation counter

COUNTS PER MINUTE

Push to start

Turn RED KNOB counterclockwise to stop.

Record average background COUNTS PER MINUTE.

Turn RED KNOB clockwise to stop.

Record average COUNTS PER MINUTE for each absorber.

TRY THE QUESTION, PUSH BUTTON "Q"

Q

A

B

C

Figure 1.

2. *A scintillation detector.* The scintillation detector is a Nuclear-Chicago No. 412 with a gamma-ray crystal. (An equivalent instrument could be used.)
3. *A counts-per-minute meter.* The count rate meter is a Classmeter II. (An equivalent instrument could be used.)
4. *Eight small discs of lead of different thicknesses mounted on the periphery of a large rotating disc.*

The source and the counter are well collimated so that the source emits a narrow beam to the counter and the counter receives very little radiation from other directions. The visitor may rotate the large disc to place any thickness of lead or merely air between the source and the counter.

PROCEDURE

Visitors are confronted with the two questions conspicuously printed on the unit.

The casual visitor probably will interpose different thicknesses of lead in the gamma path and note that the count readings are different without studying the relation between readings and lead thickness. He will then insert the card, read the question, and guess at an answer.

The average visitor probably will attempt to observe a relation between count readings and thickness without taking any written data. He will attempt to deduce a correct answer from his visual observation.

The serious visitor or a student probably will take data, subtract the background reading, and draw a curve. Students should be furnished an instruction sheet prepared for this purpose.

Since the needle of the count meter swings back and forth constantly, the observer will have to take an average reading over a period of about 30 to 60 seconds.

COPY ON UNIT

Upper Right

What thickness of lead will absorb one-half of the gamma rays?
Would double this thickness of absorber reduce the radiation to zero?

Lead Absorber	None	1	2	3	4	5	6	7	8
Thickness in Centimeters	0	0.4	0.6	0.8	1.0	1.2	1.3	1.5	2.5

Lower Left

Push button to start.

Turn RED KNOB counterclockwise to stop.

Record average background COUNTS PER MINUTE.

Turn RED KNOB clockwise to stop.

Record average COUNTS PER MINUTE for each absorber.

TRY THE QUESTION; PUSH BUTTON Q.

COPY ON RESPONSE-BOX SLIDES

QUESTION: A certain beam of gamma rays is sent through lead blocks of different thicknesses. Due to absorption, the incident-beam intensity of 100 percent is reduced to one-half, or 50 percent, in passing through 1 millimeter of lead. On sending this original beam through 3 millimeters of lead, the intensity would be reduced to:

- A. 12.5 percent B. 25 percent C. 33.3 percent

A. RIGHT. It is of interest to note that, although gamma rays have great penetrating power, they are not the most penetrating of all the known atomic particles. Elementary particles called neutrinos have such great penetrating power most of them may pass through the earth without being stopped. Like gamma rays, however, they travel with the speed of light.

B. WRONG. If a sheet of lead 1 millimeter thick absorbs half of an incident beam of gamma rays, a second millimeter sheet located behind it will absorb half of the beam entering it, or 25 percent of the original beam. The third millimeter of lead will absorb half of the beam entering it, or 12.5 percent of the original beam.

C. WRONG. *(Same copy as for B.)*

Differential Absorption

The visitor examines the extent to which different materials of the same thickness absorb gamma radiation (see Fig. 2). He observes on a scaler the different intensities of gamma radiation passing through nine materials. He may record the readings and make a plot of radiation versus density.

Samples containing various proportions of lead and concrete could be substituted in this exhibit.

A pad in front of the unit actuates a counter when anyone steps on it; thus the number of people coming to the unit is recorded. The pad turns the unit off when the visitor leaves.

A response box built into the unit contains a question with three multiple-choice answers. This box can be operated only when an answer card is inserted in a slot; the answer chosen by the visitor is recorded by a hole punched in the card. When a wrong answer is chosen, an explanation is flashed on a screen.

Supplementary equipment is available for use with the response box to record:

1. The length of time the visitor spends at the unit.
2. Whether or not he completes the procedure.
3. Whether or not he obtains the correct answer.
4. The number of people operating the unit during each hour.

PURPOSE

The purpose is given on the face of the unit in the two questions:

Which material as a shield would protect you best from exposure to gamma rays (X rays)?

For equal thickness, which of these materials is the best absorber?

EQUIPMENT

The following equipment is located behind glass, is well labeled, and is operated by knobs and buttons:

1. *A gamma source.* The source is 30 microcuries of sodium-22. Dr. Hans Weltin, who designed the machine, suggests that cobalt-60 be used in the future.

N-32

Differential Absorption

Absorber Materials

- 1 Air
- 2 Wood
- 3 Glass
- 4 Lead Glass
- 5 Cement
- 6 Copper
- 7 Aluminum
- 8 Iron
- 9 Lead

Which material as a shield would protect you best from exposure to gamma rays (or x rays)?
For equal thickness, which of these materials is the best absorber?

Gamma rays from the nuclei of atoms (like x rays and visible light rays) are electromagnetic waves and travel with the speed of light in free space.

Push to start

Select any one of the nine absorbers to be tested by turning knob until black mark on wheel lines up with pointer. Name of absorber material in gamma ray path is illuminated in table. Observe average count rate meter reading. Repeat your observations for all materials shown in table.

Figure 2.

2. *A scintillation counter.* The detection tube is a Nuclear-Chicago No. 412 scintillation tube with a gamma-ray crystal. (An equivalent instrument could be used.)
3. *A counts-per-minute meter.* The count rate meter is a Classmaster II. (An equivalent instrument could be used.)
4. *Eight small discs of different materials of the same thickness mounted on the periphery of a large rotatable disc, with one opening for air as a material.*

The source and the counter are well shielded with lead so that the source emits a narrow beam to the counter and the counter can receive very little radiation from any other direction. The visitor may rotate the large disc so that any of the materials will intervene between the source and the counter.

PROCEDURE

Visitors are confronted with the two questions conspicuously printed on the unit.

The ordinary visitor will interpose different materials in the gamma path and note that the count rate readings are different. He will probably observe that the heavier materials result in the lower readings. He will then insert the card, read the question, and choose an answer.

The serious visitor or a student probably will take data, subtract the background reading, and draw a curve of counts per minute against density of the material. Students should be furnished an instruction and data sheet prepared for this purpose.

Since the needle of the meter swings back and forth constantly, the observer will have to estimate an average reading over a period of about 30 to 60 seconds.

COPY ON UNIT

Top

Absorber Materials

1 Air	Which material as a shield would protect you best from exposure to gamma rays (or X rays)?
2 Wood	
3 Glass	
4 Lead Glass	For equal thickness, which of these materials is the best absorber?
5 Concrete	
6 Copper	
7 Aluminum	Gamma rays from the nuclei of atoms (like X rays and visible light rays) are electromagnetic radiation and travel with the speed of light in free space.
8 Iron	
9 Lead	

Lower Right

Push button to start.

Select any one of the nine absorbers to be tested by turning knob until black mark on wheel lines up with pointer. Name of absorber material in gamma-ray path is illuminated in table. Observe average count rate meter reading. Repeat your observations for all materials shown in table.

COPY ON RESPONSE-BOX SLIDES

QUESTION: When gamma rays from a radioactive source pass through matter, some are quickly absorbed, while others penetrate to great depths. Which of the following common, inexpensive materials is the best absorber of gamma rays?

A. Wood B. Aluminum C. Lead

A. WRONG. The greater the density of a material, the better it is as an absorber of gamma rays. Of the three materials, wood, aluminum, and lead, the latter is the best absorber. We suggest that you try this exhibit again to verify this result.

B. WRONG. *(Same copy as for A.)*

C. RIGHT. Because lead is such a good absorber and is the least expensive of the heavy metals, it is commonly used around an X-ray tube as well as on the walls of a room to protect a patient and a medical doctor, especially from intense X-radiation. Gamma waves, like X rays, are electromagnetic radiation, and both travel through space with the speed of light.

Backscattering

In this machine (see Fig. 3), eight different elements ranging in atomic weight from aluminum (26.98) to lead (207.19) can be rotated into position in front of the beta-emitter source. The backscattering from each element is registered separately on the scaler. These results can be compared with each other and with the backscattering from air alone and can be observed as counts per unit of time. The operator should have paper and pencil to record the backscatter for each of the eight elements and air.

The script points out that beta rays are high-speed electrons ejected from the nuclei of radioactive atoms. When beta rays enter matter, some pass on through, some are absorbed within the matter, and some bounce around and come out in other directions. Some are even turned back in the direction from which they came. This is called backscattering.

OPERATION

As with several other exhibit devices, power is turned on when an observer steps on the mat in front of the exhibit. There is a start button, a count button, and a reset button. Each of the metals is oriented in the proper position in front of the target by lining up a pointer on the scintillation counter with the center of the metal disc. The count button is held down for 1 minute per trial. This would give a minimum of 9 minutes per run of the sequence of metals and air. The metals are aluminum, iron, copper, molybdenum, silver, carbon, tungsten, and lead. After performing the sequence, the observer answers the following response-box question.

COPY ON RESPONSE-BOX SLIDES

QUESTION: When fast-moving beta particles (electrons) strike a metal plate, some of them pass into the metal and stop, while others bounce off as if they were rubber balls. The latter action is called backscattering. Which of the following metals do you think would produce the greatest amount of backscattering?

A. Aluminum B. Copper C. Lead

A. WRONG. The backscattering of beta particles increases with the number of electrons and positive charges present in the atoms of the target. Since each lead atom contains many more positive and negative charges than does aluminum or copper, of these three elements, lead is the most effective metal to produce backscattering. We suggest that you try this exhibit again to verify this result.

N-34

Back Scattering

No Back Scattering	Atomic Number	Atomic Weight
Aluminum	13	26.98
Iron	26	55.85
Copper	29	63.54
Molybdenum	42	95.94
Silver	47	107.87
Cerium	58	140.12
Tungsten	74	183.85
Lead	82	207.19

What kind of atoms produce the greatest amount of back scattering of high speed electrons?

What is the relation between back scattering and atomic weight?

Beta rays are high speed electrons ejected from the nuclei of radioactive atoms.

When such beta rays enter matter, some of them pass on through, some are absorbed within, while some bounce around and come out in other directions.

Some are even turned back in the direction from which they came. This is called back scattering.

Push to start Count button

Turn knob until pointer lines up with vertical mark on rim of wheel.
Note name of metal in table.

Push to reset scaler to zero.

Hold down count button for one minute. Note count.

Repeat for other metals and hole in wheel.

Figure 3.

B. WRONG. (*Same copy as for A.*)

C. RIGHT. As beta particles enter any material medium, they must pass by negatively charged electrons and positively charged nuclei. The repelling forces of the electrons and the attracting forces of the nuclei deflect them so that they follow random paths.

SOME SPECIFICATIONS

Across the front	33 inches
Depth	31 inches
Height	75 inches
Voltage required	110 volts alternating current
Power requirements	Nominal
Weight	250 pounds

EQUIPMENT

The *scaler* is a Nuclear-Chicago model 8770. (An equivalent instrument could be used.)

The *radioactive source* is 0.5 microcurie of strontium prepared by Dr. Hans Welton, designer of the machine. He formed a tiny well on a sheet of Mylar with rubber cement. He then dropped the radioactive strontium liquid into the well drop by drop and evaporated the liquid. He then closed the well with rubber cement and inserted the sheet into the container in the machine.

The *scintillation counter* is a Nuclear-Chicago No. 412. (An equivalent instrument could be used.) The tube has a beta crystal for the window.

The *thickness of each target* is approximately one-fourth inch.

Suggestions for varying this exhibit include a target of water or something approximating the human hand. People are most interested in finding out how much backscatter there is from human flesh and bone. They are also interested in comparing the backscatter with the amount of radiation that passes on through. This comparison might be made by using larger, but fewer, targets.

Random Counting

The four sentences in the instructions at the top of the machine (see Fig. 4) and the question "Is radioactive decay regular or random?" tell the story of this device.

As with several of these machines, stepping on a mat feeds power into the circuits. The operator then pushes the start button. After positioning the radioactive source, the operator pushes the count button. While this button is held down, the scaler is counting the pulses received from the radioactive cesium. There is another button that resets the scaler to zero.

The operator can make an unlimited number of readings for any position of the source along the scaled track. He must have a good memory or a piece of paper to record his total if he makes more than two or three. As for some other units, it is suggested that students be given data sheets. (Improvement of this unit might include an adding-machine device that would enable the visitor to record each reading, the total for a position, and the average.) A speaker inside also permits him to recognize the fact that the disintegration is random. When he walks away, the device shuts off automatically.

COPY ON RESPONSE-BOX SLIDES

QUESTION: In a quantity of radium the size of a pinhead, there are more than a million million radioactive atoms. The statement that the half-life of radium is 1600 years means that the individual atoms disintegrate:

- A. Simultaneously at the end of 1600 years
- B. At a regular periodic rate
- C. By pure chance at an irregular rate

A. WRONG. Atomic nuclei disintegrate by pure chance, and all of them disintegrate in a purely random manner. We suggest that you try this exhibit again to verify this result. Listen to the individual counts you can hear in this exhibit and watch the haphazard counting of the disintegrations on the scaler detector.

B. WRONG. *(Same copy as for A.)*

C. RIGHT. The disintegration of any one atomic nucleus is one of pure chance. A half-life of 1600 years for radium means that if you could fix your attention on a single atom the chances would be fifty-fifty it would disintegrate in 1600 years.

N-36

Random Counting

Is radioactive decay regular or random?

Turn knob to put source in any position.
Hold down count button for ten seconds. Observe
count on scaler. Reset scaler to zero and repeat for
several other ten-second intervals.
Is radioactive decay regular or random?

Figure 4.

SOME SPECIFICATIONS

Across the front	38 inches
Depth	34 inches
Height	75 inches
Voltage required	110 volts alternating current
Power requirements	Nominal
Weight	250 pounds

EQUIPMENT

The exhibit is hung inside an extremely strong welded-steel frame.

The *scaler* is a Nuclear-Chicago model 8770. (An equivalent instrument could be used.)

The *detector tube* is a regular Geiger tube for detection of beta rays.

The *radioactive source* is a standard 10-microcurie sealed source of cesium.

A suggested variation to this basic exhibit is to incorporate means of showing not only that the rate of disintegration is random but that it cannot be altered by heat, cold, or other physical forces. This might provide a very entertaining and interesting adjunct to this exhibit.

Inverse-square Law

Since this picture (Fig. 5) was taken, the formal title and text have been prepared and installed in the machine. The title across the front at the top of the machine reads "INVERSE-SQUARE LAW." No text or description appears above the counter and scale. The tube at the left, at the zero position on the scale, is titled "Scintillation Counter," and the source is titled "Cesium-137, Alpha-ray Emitter." At the extreme right just below the scale is a lead shield that can be rotated in front of the source after it has been moved all the way to position 4 on the scale. This essentially cuts off the emissions and enables the operator to read background count level. The meter is titled, "Count Rate Meter."

INSTRUCTIONS

Push start button.

1. Turn yellow knob to move source to extreme right.
2. Turn blue knob to shield source with lead.
3. Read average background radiation on count rate meter.
4. Turn blue knob to remove shield as far as it will go.
5. Move source to 20-centimeter distance mark. Note count rate. Subtract background to get true count rate.
6. Repeat step 5 for the 40-centimeter and 60-centimeter marks.

OPERATION

The operator may have some difficulty unless he has had experience with meters of this sort and experiments of this type as he tries to reach a decision on what the count rate is. He will need to have paper on which to record the results for later comparison.

After completing the experiment, the operator may answer the following question in the response-box unit located at the right in the control panel.

COPY ON RESPONSE-BOX SLIDES

QUESTION: Gamma rays from a tiny radioactive source are found to give 9,000 counts per minute when a detector is placed 10 centimeters away. When the detector is placed 30 centimeters from the source, the intensity would be approximately:

Figure 5.

A. 9,000 counts per minute B. 3,000 counts per minute C. 1,000 counts per minute

A. WRONG. The intensity of radiation from any source does not increase with distance; it decreases.

By operating this exhibit, you will find that the intensity of gamma rays varies inversely as the square of the distance from the source. At three times the original distance, the intensity will therefore drop to one-ninth of 9,000 counts per minute, or 1,000 counts per minute. We suggest that you try this exhibit again to verify this result.

B. WRONG. The intensity of gamma rays varies inversely as the square of the distance from the source. At 30 centimeters the distance is three times the 10-centimeter distance; so the intensity drops to one-ninth of 9,000 counts per minute, or 1,000 counts per minute.

C. RIGHT. There is little absorption of gamma rays by the air so that most of them leaving the source can reach the detector if it were a meter or two away. Like light, the particles travel in straight lines until they hit some object and are deflected.

SOME SPECIFICATIONS

Across the front	38 inches
Depth	34 inches
Height	75 inches
Voltage required	110 volts alternating current
Power required	Nominal
Weight	250 pounds

EQUIPMENT

The *scaler* is a Nuclear-Chicago model 8770. (An equivalent instrument could be used.)

The *radioactive source* is cesium-137, which was prepared by Dr. Hans Weltin.

The *scintillation counter* is a Nuclear-Chicago No. 412. (An equivalent instrument could be used.)

This device could be improved by an arrangement enabling the user to plot a curve of distance versus count rate. This might be done electrically as in the dice-game machine, on a sheet of paper, or on the type of pressure-sensitive material that erases easily for immediate reuse. It should be pointed out that sufficient distance is a very convenient and effective form of shielding.

Half-life of Silver

This device will enable the visitor to irradiate a sample of silver and then measure the half-life of a silver radioisotope produced by the irradiation.

The photographs (Figs. 6 and 7) show the front and rear of the unit as it neared completion. This type of construction is typical of the six devices which are used for basic radioactivity experiments and are described in the first section of this report.

In this half-life experiment, a silver sample is subject to neutron bombardment in a well-shielded neutron source at a safe distance from the visitor operating the device.

The sample is driven by compressed nitrogen from the exhibit device to the neutron source and back through a 40-foot length of flexible plastic tubing. The nitrogen tank and plastic tubing can be seen in Fig. 7.

After irradiation, the sample comes to rest before the radiation detector on the right of the cabinet in Fig. 6. A timing mechanism is in the middle of the cabinet, and a count rate meter is on the left. A small part of the sample which has been converted to silver-110 by the neutron bombardment decays with a half-life of 24.4 seconds.

Student visitors should be given instruction sheets with spaces for data recording and a piece of graph paper for curve plotting.

Figure 6.

Figure 7.

Linear Accelerator

Figure 8 shows Dr. Harvey E. White, Director of the Lawrence Hall of Science, standing at the operating controls of this mechanical analogy of a linear accelerator; Fig. 9 pictures the control end of the machine.

Figure 10 shows the panels that appear white in Fig. 8. At the far end of this photograph is the ejector mechanism, which feeds large steel balls, representing electrons, up onto a metal track one at a time. Sections of the track rock, accelerating each ball in turn down the "drift channel." There are nine sections of track, each longer than the preceding one, and their movement is synchronized with red and green lights (signifying positive and negative charges) to indicate that electric fields are responsible for the acceleration in a real accelerator.

At the end of the run the ball drops out of sight under the primary target. Out of this target comes a flash of light representing a gamma ray (see Fig. 9). This ray leads into the secondary target, out of which comes one of these four events: (1) Two steel balls are released and pass out under the electromagnet. Magnetically controlled vanes give them a wide angle deflection, and they travel across the plate and fall in the slot at the end, simulating an *electron pair*. (2) Two steel balls come out, the deflection is much smaller, and this simulates a *pion pair*. (3) The next event releases one ball, and the event is a *photo-electron*. (4) The remaining event is an electron and a gamma ray. As each event occurs, the appropriate diagram at the bottom of Fig. 9 lights up.

These events are not in sequence and do not repeat every fourth time. Stepping relays control the sequence, which is long enough so that it takes several runs of the machine to repeat each event. In Fig. 9 one can see the faint paths left by the steel balls referred to above. After the operator presses the button and observes the events, he is ready for the response-box question.

COPY ON RESPONSE-BOX SLIDES

QUESTION: An atomic accelerator is an electromagnetic device for speeding up atomic particles to high energies, whereupon they are allowed to bombard a target and produce nuclear disintegrations. The linear accelerator is one such device, and it is used principally for accelerating:

- A. Electrons B. Protons C. Deuterons

Figure 8.

Figure 9.

Figure 10.

- A. RIGHT.** When electrons are accelerated to high speed by a linear accelerator and then allowed to impinge upon any solid object as a target, they produce a beam of high-energy gamma rays. These gamma rays, when incident on a second target, produce nuclear collision events, such as a photo-electric effect, a Compton effect, an electron pair, and a pion pair.
- B. WRONG.** Linear accelerators are designed to produce beams of very high speed electrons. The paths along which electrons are accelerated cannot be swerved as in a cyclotron since, moving in a circular path, they would radiate energy as fast as they receive it. We suggest that you try this exhibit again.
- C. WRONG.** Linear accelerators, large and small, are designed for accelerating electrons to high speed close to the speed of light. Their paths must be straight since, moving in a curved path at very high speeds, they will radiate energy as fast as they receive it. We suggest that you try this exhibit again.

SOME SPECIFICATIONS

Length	154 inches (about 13 feet)
Depth	54 inches
Height	53.5 inches
Voltage required	110 volts alternating current
Power required	Nominal
Weight	Several hundred pounds

SUGGESTIONS

If this kind of exhibit were coupled with programmed consoles like those used with the Periodic Table exhibit, the significant accelerators could be shown along with some of their discoveries and unique features. A well-formulated program consisting of slides, movie film, and audio tape, plus the opportunity for observer response, would make an informative and a challenging display.

Mechanical Cyclotron

The machine pictured in Fig. 11 illustrates in a mechanical way the operation of the first cyclotron, the tiny 3-inch-diameter machine conceived and built by Ernest O. Lawrence in 1930. Obviously it illustrates the basic principles of all cyclotrons. It is an excellent companion for the linear accelerator in the preceding section.

The visitor-operator presses a start button and selects a particular target from a choice of three. After he has made his selection, a light goes on indicating that the selection has been made properly, and the "dees" begin to rock. The steel balls feed into the center of the rocking plates and follow the tracks in ever-widening circles until they reach the edge, where they leave the perimeter in a straight line, go through the target, are deflected, and fall in the slot at the far end of the machine.

The text on the machine reads as follows:

In a Lawrence cyclotron atomic particles, such as protons, deuterons, or alpha particles, are accelerated to very high speeds as they move in ever-widening semicircles in a magnetic field. As these particles pass through matter, called a TARGET, many of them collide with nuclei of atoms and cause reactions. Nuclear fragments flying out from these reactions can be identified by observing how their paths are bent in passing through the strong field of an ELECTROMAGNET. In the mechanical cyclotron operating here, the steel balls, representing protons or deuterons, are accelerated as they pass from one semicircular plate to the other. At the end of the outermost track, their path is straightened out, and they are made to enter one of three targets representing (1) Beryllium, (2) Aluminum, or (3) Lithium. The balls emerging from the TARGET represent neutrons, ${}_0^1\text{n}$; alpha particles, ${}_2^4\text{He}$; or protons, ${}_1^1\text{H}$, respectively. A proton is a hydrogen nucleus; an alpha particle is a helium nucleus; and a deuteron is a deuterium, or heavy hydrogen, nucleus.

INSTRUCTIONS ON THE CONTROL PANEL

Hold down here and rotate knob to select target 1, 2, or 3. Push here to start cyclotron only when diagram 1, 2, or 3 is illuminated. Three block type diagrams each in a color matching the target selected aid in making the choice clear.

Figure 11.

COPY ON RESPONSE-BOX SLIDES

QUESTION: An atomic accelerator called the cyclotron is a device for speeding up hydrogen or deuterium nuclei to high energies. When a beam of high-speed protons strikes a beryllium-metal target, the beam of particles emerging from the other side is composed of:

- A. Alpha Particles B. Neutrons C. Electrons

A. WRONG. When a high-speed proton collides with a beryllium nucleus in a metal target, it is captured, and with each capture a neutron is ejected.

protons + beryllium target $\rightarrow$ neutrons

We suggest that you try this exhibit again to verify this result.

B. RIGHT. When a high-speed proton collides with a beryllium nucleus, a neutron is ejected.

Obeying the law of conservation of momentum, the neutrons recoiling forward from many of these events constitute a neutron beam. Such a beam is often used for bombarding other targets.

C. WRONG. *(Same copy as for A.)*

SOME SPECIFICATIONS

Width	62 inches
Distance front to back	83 inches
Height	37 inches
Voltage required	110 volts alternating current
Power required	Nominal
Weight	Several hundred pounds

Hidden-target Pinball Machine

The hidden-target pinball machine is a mechanical analogy device with which the visitor shoots steel balls at a target hidden under a disc in an effort to determine the shape of the target. Displayed on the machine are five suggested shapes for the hidden target. By rotating the target and the disc and noting the directions in which the balls bounce, the operator can determine which of five suggested targets is hidden under the disc. This machine is shown in Fig. 12.

Ernest Rutherford shot helium nuclei at thin gold foils and deduced the structure of the atom from the way the helium nuclei bounced. In this experiment, as in the pinball machine, the target was not visible.

At the Lawrence Hall of Science, there are four of these hidden-target machines, each with a differently shaped target. The top of each machine is covered with heavy glass.

The procedure is simple and is given clearly in the copy on the unit. There is no specific point at which one begins and ends. There are no questions.

The object of the device is to illustrate that a person can determine by indirect observation and reasoning the shape of what he cannot see.

(Continued on following page.)

Figure 12.

COPY ON THE TOP OF THE MACHINE

At Front

Scientist E. Rutherford shot helium nuclei at metal foils and determined the nature of the invisible nuclei of the atoms.

Which of these five targets is under the disc? Shoot ball at it to find out.

At Right Front

Rutherford Scattering

The text on the device shown in Fig. 13 reads as follows:

When high-speed atomic projectiles like protons (hydrogen nuclei) collide with atomic nuclei, they are usually deflected to one side or the other. This is called Rutherford scattering or elastic scattering.

If a proton has a high enough velocity and makes a head-on collision, it may be captured.

The crater represents the nucleus of a single atom and the steel ball you shoot represents the proton. The hill provides an increasing force as the steel ball (proton) approaches the slope (nucleus) and simulates the repelling force between two positively charged bodies.

The questions inform the operator that he must try to set his tension on the shooter spring and his aiming angle so that the ball will mount the potential hill or barrier and drop into the crater (nucleus).

These questions are written on litho film under the glass on the top of the device:

1. Can you roll the ball into the crater?
What spring setting is best for capture?
2. Can you roll the ball into one of the 150° pockets?
What spring scale and angle scale readings did you use?

A line diagram on the right front of the device gives the following information in relation to features of the unit:

The large metal cone with the crater in the center represents the barrier, or potential hill, simulating the repulsion of a positively charged particle as it approaches a positively charged nucleus.

The degree marks around the perimeter of the machine make it possible to check the angle of the ball rebound.

The ball-shooting mechanism has a scale and pointer, and the farther back the plunger is pulled, the greater the tension of the spring. After the correct setting is found, it should be possible to duplicate the tension and angle and put the steel ball in the crater with every shot. There is also an angle scale for aiming the ball directly at the crater or a few degrees to the right or the left of it.

The text points out the following knobs and instructions:

1. The pinball shooter. Pull knob to shoot. Move sideways to shoot at different angles.
2. Rotate to bring balls to shooter.
3. Turn to lock shooter in place.

Figure 13.

COPY ON RESPONSE-BOX SLIDES

QUESTION: When a high-speed proton with its positive charge enters an atom and approaches the nucleus, it is deviated in its path and recoils off in another direction. The deflecting force is described as being due to:

- A. Repulsion by the nucleus
- B. Attraction by the surrounding electrons
- C. A mechanical collision of the two spheres

A. RIGHT. The repelling force exerted on the proton by the positive charge of the massive nucleus deflects the proton in its path. The attractive forces exerted by the passing proton on the relatively lightweight electrons, however, may pull one or more of the electrons away from the atom.

B. WRONG. The proton's mass is 1836 times the mass of an electron; so the attractive forces deflect the electrons but have little effect on the proton's motion. The mass of the nucleus, however, is much greater than that of the proton, and the proton is thereby deflected by the large repelling force from the nucleus. We suggest that you try this exhibit again to verify this result.

C. WRONG. *(Same copy as for B.)*

SOME SPECIFICATIONS

Width	41 inches
Distance from front to back	55 inches
Height	37 inches
Voltage required	110 volts alternating current
Power required	Nominal
Weight	250 pounds

Rutherford Thick-target Machine

Standing in front of this exhibit device, shown in Fig. 14, one's attention is first drawn to 19 aluminum cones on a disc in the center of a circular plate some 3 feet in diameter. The area around the circular plate is divided into more than a score of compartments numbered in degrees in both directions from a point opposite the visitor-operator. Close to the operator is a pinball type plunger with which he can shoot steel balls at the cones.

In operation, the disc with the cones on it rotates gently a few degrees, first in one direction and then in the other, so that the aluminum spires are struck by the steel balls in a random manner.

RUTHERFORD'S WORK

Firing the metal balls five at a time and noting the compartments into which they fall duplicates in a mechanical manner, with some limitations, the famous experiment carried out by Ernest Rutherford at McGill University in 1911. Rutherford and his co-workers bombarded thin gold foils some 10,000 atoms thick with alpha particles (helium nuclei) produced by the radioactive decay of radium atoms. He observed the results of the bombardment by watching the light scintillations produced on a zinc sulfide screen as the alpha particles passed through the foil and hit the screen.

Most of the time the particles passed almost straight through and were not deflected; this indicated that the atom was mostly empty space. On moving his screen around to other positions, represented here by the compartments located around the perimeter, he found that scintillations were produced at other locations, even straight back from the target foil. This was as surprising as if a 14-inch cannon shell fired at tissue paper had bounced straight back upon hitting the paper.

From these experiments Rutherford reasoned that each atom of gold occupies a spherical volume of a diameter of some 10^{-8} centimeter and the nucleus a volume with a diameter of some 10^{-13} centimeter. He further proposed that the nucleus is positive, that the electrons are found outside the nucleus, and that most of the mass of the atom is in the nucleus.

Figure 14.

OPERATING INSTRUCTIONS

The text on the machine reads as follows:

- 1. Push green button on the left to set disc turning.
- 2. Rotate large metal knob to bring steel balls into shooting position.
- 3. To shoot balls, pull back red knob and release.
- 4. Repeat shooting until all the balls are fired.
- 5. Note the number of balls in the different sockets. To repeat the operation, push the red button so that the central disc rises and the balls fall inside.

A question with answers for a response box had not been prepared when this publication went to press.

ATOMIC COLLISIONS

Scientists have determined the size of the atomic nucleus by shooting atomic particles at metal targets composed of millions of atoms. Many of the particles bounce off the individual nuclei within the target as if they were perfectly elastic spheres. This is called elastic scattering.

The small cones at the center of this apparatus represent atomic nuclei in a solid target, and the steel balls represent atomic particles. The cone shape is analogous to the electric potential around an atomic nucleus.

SOME SPECIFICATIONS

Width	41 inches
Distance front to back	55 inches
Height	37 inches
Voltage required	110 volts alternating current
Power required	Nominal
Weight	250 pounds

Periodic Table

This exhibit unit (see Figs. 15, 16, and 17) is designed so that three different configurations of the periodic table are available upon command in one structure. If one is familiar with the triangular-faced advertising displays that smoothly change from one face to a second and finally to a third, then he can easily understand the operation of this machine. Each of the three faces is distinctively different in color, layout, and kind of scientific information shown.

The elements are arranged in the commonly accepted long form with 18 vertical columns, beginning with hydrogen on the left and ending with helium at the extreme right in column 18. The lanthanide and actinide series are placed below the main body of the table, and they will rotate as a group of 14 elements. Space is provided for future discoveries of elements 104 to 118, which scientists feel will follow lanthanum in the main body of the table.

OPERATION

A master control board has the same layout as the table. This board contains separate buttons for lighting each of the elements; thus each element is controlled individually. Two other buttons make it possible to light all the elements or to cancel all lights that are on. A blinker mechanism is used to show naturally radioactive elements and man-made radioactive isotopes.

The table is unique in that each column can be turned individually without jamming with its neighbor. Each of the 18 columns can be on any of the 3 faces at any time; on command from the control panel, they will all go to a single desired face, be it face 1, 2, or 3.

A lecturer standing before the control panel can show periodic relations or the information listed in the legends for Figs. 15, 16, and 17. Observers with normal vision can read all these data from a distance of 80 feet.

FEATURES

The table was designed to dominate the Hall of Chemistry in the Lawrence Hall of Science. It is 17 feet high, 23 feet long, and 5 feet deep. The panel for each element measures 12 by 15 inches. Face 1 is silk screened in the colors black, blue, and red on milk-white plastic. Face 2 is reproduced photographically on heavy litho line-process film, and the clear letters

are covered with colored gelatins through which the lights shine, highlighting each individual bit of information. Face 3 is again silk screened in color on yellow and blue plastic, separating metals and nonmetals.

Face 2 was designed for use in physics and radioactive chemistry lectures, and face 3 is more pertinent to chemistry studies. As demonstrations are performed in front of the table, the reasons behind the behavior of the elements can be clearly and dramatically pointed out by lighting and rotating the columns of elements.

In the gap at the top of the table (see Figs. 15, 16, and 17) are two rear-projection screens. Two remotely controlled random-access slide projectors have been installed behind the screens, and they will be used to aid the lecture-demonstrator in the development of his material. It will also be possible to program a slide show related to the various aspects of the history of periodic tables in general and to other features of this particular table. The voice narration will be keyed to change the slides as desired.

PROGRAMMED INSTRUCTION FOR INDIVIDUAL VISITORS

When the table is not in use by lecturers, it can be manipulated by visitors at four consoles. Many other visitors can observe. Each console is connected to a group of elements. Programs have been written to automate the groups by use of a Cousino tape recorder, with supplemental presentation from a Kodak Carousel slide projector and a Fairchild continuous-loop movie projector. (Equivalent equipment may be used.)

The visitor is led through a simple program of instruction relative to a small number of chemical elements in a family. As the tape progresses, the visitor-operator is asked to answer questions by lighting the elements and rotating the columns. The viewer is involved in a reaction between what he sees and hears and the big table. The program gives him the answers after he has carried out his operations. Very simple programs have been written and filmed for the less experienced viewers, and more sophisticated ones are planned for more mature viewers. In a matter of minutes, the slide tray, movie loop, and tape cartridge can be changed in the console. Interesting aspects of radioactivity could be brought out with different programming.

CONSTRUCTION DETAILS

Triangular aluminum castings separate the elements from each other vertically and form light-tight cells. Four 15-watt bulbs light each cell, and these are undervolted for long, trouble-free operation. Small baffles dissipate the heat buildup that occurs when all elements are lighted at once. Each column rotates around a central fixed shaft; this arrangement avoids the use of slip rings for electrical contact. Electric clutches and an electric brake system control precisely the starting and stopping of each column through limit switches and relays. Since each of the two tallest columns weighs only about 90 pounds, their rotational inertia is small.

All the work on the faces was done photographically. A copy of the master set of drawings for the table can be obtained from the Lawrence Hall of Science.

Dr. Glenn T. Seaborg, Chairman, U. S. Atomic Energy Commission, and Dr. Harvey E. White, Director of the Lawrence Hall of Science, at the control panel of the periodic table.

Hydrogen 1.0080 1 H																	Helium 4.003 2 He				
Lithium 6.939 3 Li	Beryllium 9.012 4 Be															Boron 10.811 5 B	Carbon 12.01115 6 C	Nitrogen 14.007 7 N	Oxygen 15.999 8 O	Fluorine 18.998 9 F	Neon 20.183 10 Ne
Sodium 22.990 11 Na	Magnesium 24.312 12 Mg															Aluminum 26.981 13 Al	Silicon 28.086 14 Si	Phosphorus 30.974 15 P	Sulfur 32.064 16 S	Chlorine 35.453 17 Cl	Argon 39.948 18 Ar
Potassium 39.102 19 K	Calcium 40.08 20 Ca	Scandium 44.956 21 Sc	Titanium 47.88 22 Ti	Vanadium 50.942 23 V	Chromium 51.996 24 Cr	Manganese 54.938 25 Mn	Iron 55.847 26 Fe	Cobalt 58.933 27 Co	Nickel 58.69 28 Ni	Copper 63.54 29 Cu	Zinc 65.37 30 Zn	Gallium 69.72 31 Ga	Germanium 72.59 32 Ge	Arsenic 74.922 33 As	Selenium 78.96 34 Se	Bromine 79.904 35 Br	Krypton 83.80 36 Kr				
Rubidium 85.47 37 Rb	Strontium 87.62 38 Sr	Yttrium 88.905 39 Y	Zirconium 91.224 40 Zr	Niobium 92.906 41 Nb	Molybdenum 95.94 42 Mo	Technetium (99) 98.906 43 Tc	Ruthenium 101.07 44 Ru	Rhodium 102.91 45 Rh	Palladium 106.4 46 Pd	Silver 107.87 47 Ag	Cadmium 112.40 48 Cd	Indium 114.82 49 In	Tin 118.69 50 Sn	Antimony 121.75 51 Sb	Tellurium 127.60 52 Te	Iodine 126.90 53 I	Xenon 131.29 54 Xe				
Cesium 132.905 55 Cs	Barium 137.34 56 Ba	Lanthanum 138.905 57 La	Hafnium 178.49 72 Hf	Tantalum 180.94 73 Ta	Tungsten 183.85 74 W	Rhenium 186.21 75 Re	Osmium 190.2 76 Os	Iridium 192.2 77 Ir	Platinum 195.09 78 Pt	Gold 196.97 79 Au	Mercury 200.59 80 Hg	Thallium 204.37 81 Tl	Lead 207.19 82 Pb	Bismuth 208.98 83 Bi	Polonium (209) 84 Po	Astatine (210) 85 At	Radon (222) 86 Rn				
Francium 223 87 Fr	Radium (226) 88 Ra	Actinium 227 89 Ac	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18				
Cerium 140.12 58 Ce	Praseodymium 140.91 59 Pr	Neodymium 144.24 60 Nd	Promethium (147) 61 Pm	Samarium 150.35 62 Sm	Europium 151.96 63 Eu	Gadolinium 157.25 64 Gd	Terbium 158.93 65 Tb	Dysprosium 162.50 66 Dy	Holmium 164.93 67 Ho	Erbium 167.26 68 Er	Thulium 168.93 69 Tm	Ytterbium 173.04 70 Yb	Lutetium 174.97 71 Lu								
Thorium 232.04 90 Th	Protactinium (231) 91 Pa	Uranium 238.03 92 U	Neptunium (237) 93 Np	Plutonium (242) 94 Pu	Americium (243) 95 Am	Curium (247) 96 Cm	Berkelium (249) 97 Bk	Californium (251) 98 Cf	Einsteinium (254) 99 Es	Fermium (253) 100 Fm	Mendelevium (256) 101 Md	Nobelium (259) 102 No	Lawrencium (260) 103 Lw								

Figure 15 Face 1: name of element, in black; atomic mass, in green; atomic symbol, in blue; and atomic number, in red.

Figure 16 Face 2: atomic number, in red; electronegativity, in pink; mass of isotopes, principally in yellow, the actinide series in violet; metallic radius, orange for metals; covalent radius, orange for non-metals; relative size, an orange-colored circle; crystal structure, in green; and background, in black.

The periodic table is displayed on a black board with a house-like shape. The board has two rectangular cutouts in the upper center. The periodic table is printed on a light-colored card with various colored text: atomic numbers in red, first ionization energy in orange, oxidation states in orange, ionic radius in green, relative size of ion as a green circle, and spd configuration in black and red. The elements are arranged in rows and columns, with some elements missing in the lower part of the table.

Figure 17 Face 3: atomic number, in red; first ionization energy in electron volts, in orange; oxidation states, in orange; ionic radius, in green; relative size of ion, a green circle; and spd configuration, in black and red.

Calcium Intake

The operation of this calcium intake exhibit device can be followed in Fig. 18. The operator pushes the start button and is instructed to turn a knob indicating how many portions of each food listed on the face of the machine he consumes in one day. He will find that turning all the knobs for all the foods to the maximum number of portions and leaving the knob connected to milk at zero will register his calcium intake well below the required amount.

We have observed that young people who work the machine in the presence of their fellow students will often fudge the controls a bit to show enough calcium in their diets and later return to the machine alone for a true appraisal of their calcium intake. Most people operating the machine find that they are not getting enough calcium to maintain strong bones and teeth.

DIMENSIONS

Width	28 inches
Height	71 inches
Depth front to back	33 inches

DETAILS OF OPERATION

As knobs on the front are turned, small bulbs light up added portions of food. Compartments must screen one glass of milk from the other so that the light from one does not carry over to a second or third glass of milk. The same holds true for the other foods. As knobs are turned to more portions, more current flows through the ammeter at the top; the current flowing through the meter when all the knobs are in their final positions is a measure of the total calcium intake.

This is the first of a number of exhibit devices dealing with the general health topics of diet, smoking, and exercise.

Figure 18.

Chromatography

A chromatography exhibit device has been designed with which the visitor-operator actually performs simple analyses of two inks.

The procedure can be followed in the text on the face of the unit in Fig. 19. After the paper has been spotted with the two inks and developed for about 30 seconds in water, the dyes begin to separate into bands of different colors. This separation shows that the composition of the inks is different.

A timing device makes it impossible for visitors to keep punching the blotting-paper release button and feed out paper endlessly. The level of the ink in the tanks is maintained constant from a supply in two large reservoirs above the tanks. The tanks should be cleaned frequently.

The exhibit is extremely rigid because it is mounted on a welded steel frame.

SOME SPECIFICATIONS

Length across the face	43 inches
Depth	33 inches
Height	71 inches
Voltage required	110 volts alternating current
Power requirements	Nominal

This chromatography unit is one of several exhibit devices designed for the chemistry area of the Lawrence Hall of Science. Other devices show electrolysis of water, color of ions, conductivity of solutions, activation energy, and acid-base chemistry.

C-10

Chromatography

*There are two inks in the tanks.
Do they contain the same dyes?*

To get paper:

push button when green light is on.

Paper

To spot ink on paper:

insert paper,
and push button.

Paper Insert

Clock

To separate the dyes in the inks:

insert spotted end of paper in the slot,
and wait for HAND to go around once.

Slot

What did you discover?

Figure 19.

Dice-game Probabilities

This is one of a series of exhibit devices designed to interest and inform students and the general public about the mathematics of probability. A cage holding two dice should attract people to the device and interest them in operating it (see Fig. 20).

To the left of the cage is a large white panel that has about 200 lights concealed behind it. There are 35 horizontal lines on the panel, and across the bottom 2's, 3's, 4's, 5's, etc., are visible. Each time button 2 is pressed, a light is turned on directly above the 2 on a successively higher line. The same is true for buttons 3 through the 12. The operator rolls the cage over, and the dice may read 5 (a 4 and a 1 or some other combination making 5). The operator would then push the button with 5 on it, and a light would appear on line 1 above the 5. No more buttons will operate until the dice are rolled once again. The longer the game is played, the closer the relation to the laws of probability; the lights form a pattern closely approximating the normal curve. The game is extremely intriguing in that 4's, 5's, or some other number with a high probability may appear on several successive rolls. The column of lights will climb much faster than the 7's, which are supposed to be rolled most frequently. Just when you think some other number is going to reach the top line, the 7's usually roll; and I have yet to see a game played in which the 7's were not rolled most frequently, reaching the top line first.

INSTRUCTIONS

The possible combinations of the two dice are given in the 36 squares at the left of the machine. The text reads as follows:

	1	2	3	4	5	6
1	1	1	1	1	1	1
2	1	2	2	2	2	2
3	1	2	3	3	3	3
4	1	2	3	4	4	4
5	1	2	3	4	5	5
6	1	2	3	4	5	6

The square at the left shows the 36 possible ways of throwing a pair of dice. Note that in the 36 throws the number 7 should or can come up 6 times. The probability of throwing a 7 is $6/36$. Similarly, the probability of throwing either a 2 or a 12 is $1/36$. Throw the dice by rotating the knob. Record on the scoreboard the number thrown by depressing the corresponding button. Watch the scoreboard as the number of throws increases.

There is a "push to reset" button that turns off all the lights and returns the machine to the starting condition.

Figure 20.

COPY ON RESPONSE-BOX SLIDES

QUESTION: A bag contains 3 white balls and 4 black balls. Without seeing them, a person removes one ball. What is the probability that the ball selected is white?

A. $\frac{3}{4}$ B. $\frac{7}{3}$ C. $\frac{3}{7}$

A. WRONG. $\frac{3}{4}$ would be the correct answer if the bag contained 3 white balls and 1 black one.

B. WRONG. $\frac{7}{3}$ is impossible because the probability can never be greater than 1, or 100%.

C. RIGHT. There are 7 balls in the bag. A ball may be drawn in 7 different ways. Of these 7 possibilities 3 will be a white ball. The chance of drawing a white ball will be 3 in 7.

SOME SPECIFICATIONS

Length across the face	43 inches
Depth	32 inches
Height	73 inches
Voltage required	110 volts alternating current
Power required	Nominal
Weight	About 300 pounds

The machine is built on a rugged steel frame. It contains some 200 circuits that are conventional but time-consuming to wire.

How Good Is an Exhibit?

Is an exhibit really good when a large number of people wait in line to see it? Do people want to be challenged to participate, or do they prefer static displays? How much time does the average visitor spend at an exhibit? To what degree does he become involved? How much meaningful information does he carry away? How well does the viewer understand the objectives the designer tried to build into the exhibit? Does a good exhibit necessarily cost a lot of money?

Although a variety of attempts have been made over the years to answer such questions, in view of the amount of money spent for exhibits, there has been little testing or evaluation research.

THREE QUESTION-AND-ANSWER MACHINES

With the questions of the first paragraph in mind, the staff of the Lawrence Hall of Science has designed and built three types of question-and-answer machines, or response boxes, and is incorporating them into its exhibits. These machines are:

Model A — Contains one question with three multiple-choice answers. Small. Can be built into new exhibits or made a part of existing ones.

Model B — A free-standing console containing 10 questions, each with three multiple-choice answers. Intended for an exhibit area. Can be installed in any museum or hall of science.

Model C — A free-standing console into which different film loops, magnetic tapes, and slide trays can be plugged. Each combination of film, tape, and tray is programmed for an exhibit and electrically linked to it. Thus there can be two-way communication between the visitor and the exhibit. Different plug-in combinations are used to adapt the communication to the age or educational level of the viewer.

Model A is illustrated and discussed on pages 50 and 51, and Model B, on page 53. Model C is described on page 54.

◀ *Figure 21 Model A question-and-answer device.*

MODEL A

This is the small question-and-answer device, or response box, whose face is visible in the exhibit units in Figs. 1, 2, 3, and 4. The face, measuring only 8 by 8 inches, contains 4- by 6-inch glass, a rear-projection screen, a narrow slot for the insertion of a famous-scientist card (Fig. 23), and four push buttons labeled Q, A, B, and C (Fig. 21).

An approaching visitor turns on the exhibit unit when he steps on a floor pad containing an electrical switch. Inserting his card into the slot activates the question-and-answer device. After observing the exhibit and manipulating it as the text directs, the visitor may press the Q button. This turns on the lamp in the projector of the device which throws on the screen a slide containing a question and three possible answers. The visitor decides which of the three answers — A, B, or C — he believes to be correct and then pushes the button of his choice. Pushing any of the three buttons puts a new slide on the screen; one slide says that the answer is RIGHT, and the other two inform him he is WRONG. Simultaneously a hole is punched in the card to record the answer he selected.

The answer slides indicating a WRONG choice also contain instructions for further observation. When the visitor makes a second choice, a new slide appears on the screen with a RIGHT or WRONG answer, but no hole is punched.

After visiting 10 exhibits and having his card punched in each, the participant inserts the card in a readout box and receives a total performance score.

A plug-in attachment box (Fig. 22) containing a roll of paper tape for making a record of a variety of visitor responses is being developed and will supplement data from the readout box. The attachment box will operate in the following manner: When an approaching viewer steps on the pad in front of an exhibit, the circuit is closed, causing a hole to be punched in the slow-moving tape. When he pushes the Q button, a second hole is punched. When he presses the answer button, a third hole is punched, and the spacing will show how long he deliberated. The tape will also show whether his choice was right or wrong. Finally, when he moves away from the exhibit, the foot switch will open, recording departure and total time spent at the exhibit.

◀ *Figure 22 Tape recorder used with Model A.*

FAMOUS-SCIENTISTS CARDS

We have also created famous-scientists cards (Fig. 23) which are intended to be especially useful to a group of students and their teacher who might be interested in a particular subject area. It is hoped that these cards will have value as collectors' items, akin to baseball cards, for each will contain a picture of a famous scientist with a summary of his life and work.

Cards will be color coded for their subject areas. They will be used to activate response boxes specially equipped to receive them. Each card can activate 10 different boxes in its subject area, and each will record the first answer selected at each box by having a hole punched in it.

After the cards are fully used, the students can put them in a readout device that will score them, or the teacher can collect and score them.

Of course, use of the response boxes in connection with the scientists cards can also be tape recorded.

**Insert this end of card
in slot, with stars and
picture toward exhibit.**

Save this picture and make a
collection of famous scientists
displayed in the Lawrence Hall
of Science.

Ernest O. Lawrence—(1901 - 1958),
American Physicist, Nobel Laureate,
and recipient of the U. S. AEC Enrico
Fermi Award. He invented the cyclo-
tron, as well as a practical color TV
picture tube, and directed the science
development project by which ura-
nium-235 isotopes were first separated
in useful quantities. The Lawrence Ra-
diation Laboratory and the Lawrence
Hall of Science, on the Berkeley cam-
pus of University of California, are
named in his honor.

★	N-30 Inverse Square Law	★	N-35 Beta Ray Deflection
★	N-31 Gamma Ray Absorption	★	N-36 Random Counting
★	N-32 Differential Absorption	★	N-10 Mechanical Cyclotron
★	N-33 Half-life of Silver	★	M-21 Pythagorean Theorem
★	N-34 Back Scattering	★	M-30 Mathematical Minimum

Figure 23 Preliminary famous-scientist card.

Figure 24 Model B question-and-answer device.

MODEL B

The chief components of this machine are a random-access slide projector, a rear-projection screen, logic circuits, push-button switches with which to operate the machine, a scoring device, and recorders for evaluating visitor response (Fig. 24). Designed to cover a specific area, this device asks questions and records answers about a group of related exhibits.

Its console contains operating instructions, a projection screen that portrays the questions and answers, a readout display of the visitor's score, a question button (Q), and three answer buttons (A, B, and C).

The random-access projector is programmed with 40 slides—one for each of 10 questions and one for each of 30 multiple-choice answers.

An approaching visitor steps on a floor pad that closes a circuit; a relay turns on the machine and registers the visitor's arrival on a concealed counter. Thus the number of visitors is automatically recorded. The instruction panel lights up and invites the visitor to test his knowledge. If he walks away, the lights go out; if he stays, he may proceed with the program.

After the visitor has answered the tenth question, his total score appears on the readout face. If he leaves then or if he leaves before the sequence is completed, the machine returns to question one for the next visitor. If he stays and presses the Q button again, the score display goes back to zero, the first slide appears, and he can repeat the sequence.

The machine is built so that its questions and responses can be changed easily; thus it can be quickly reprogrammed for different audience levels.

MODEL C

This device is designed to involve a visitor with an exhibit for some length of time. Motion pictures, slides, and recorded narration carry him through an information sequence, and then he answers questions by manipulating the exhibit. The operation of this model may be compared with that of some learning machines. Its application to the periodic table exhibit is described on page 37.

A typical sequence of operations for this model response box might follow these lines. The visitor activates the "start" button. Immediately a recorded voice begins to talk to him and slides matching the narration appear on the screen. The taped voice may tell him something interesting about the exhibit or direct his attention to a specific part of it. As each point in the narration is emphasized, a new slide appears. The magnetic tape on which the voice is recorded also carries the signal for operating the slide projector. At some point in the narration, the slide projector and tape may stop, and a short motion-picture film loop may be run.

This completes the introductory, or instruction, phase of operation, designed to intrigue the visitor to become involved with the exhibit. From this point on he presses buttons or turns dials to operate the exhibit as the tape directs. The slides may present a series of questions, answered by manipulation of the exhibit. The correct answer appears on the screen after the visitor selects his answer. At the end of the series, the slide tray, the magnetic tape, and the film loop return to the "start" position to be ready for the next visitor.

In a matter of a few minutes, a new tape, film-loop cartridge, and tray of slides can be inserted and the exhibit made ready for another age level.