BASIC RESEARCH

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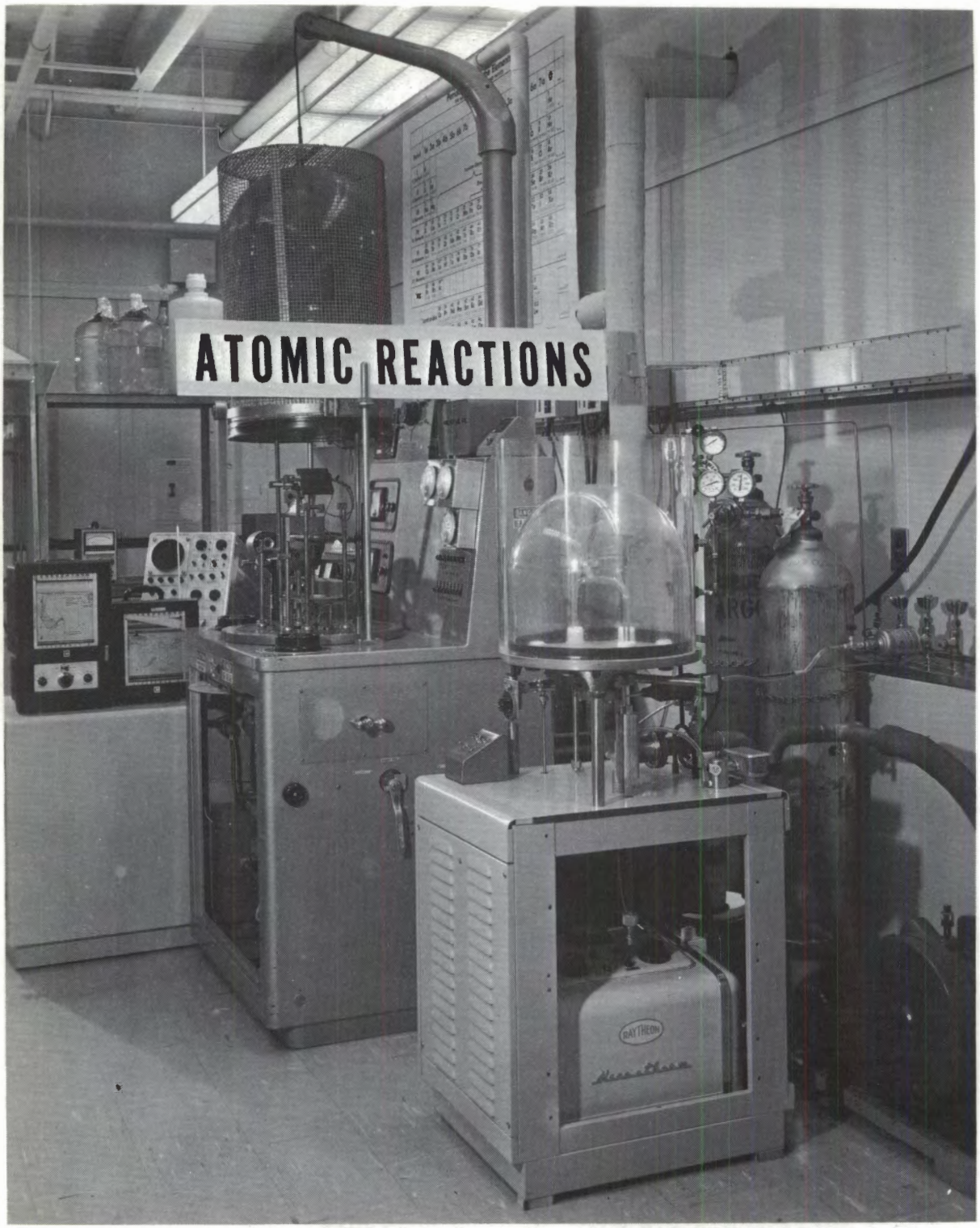
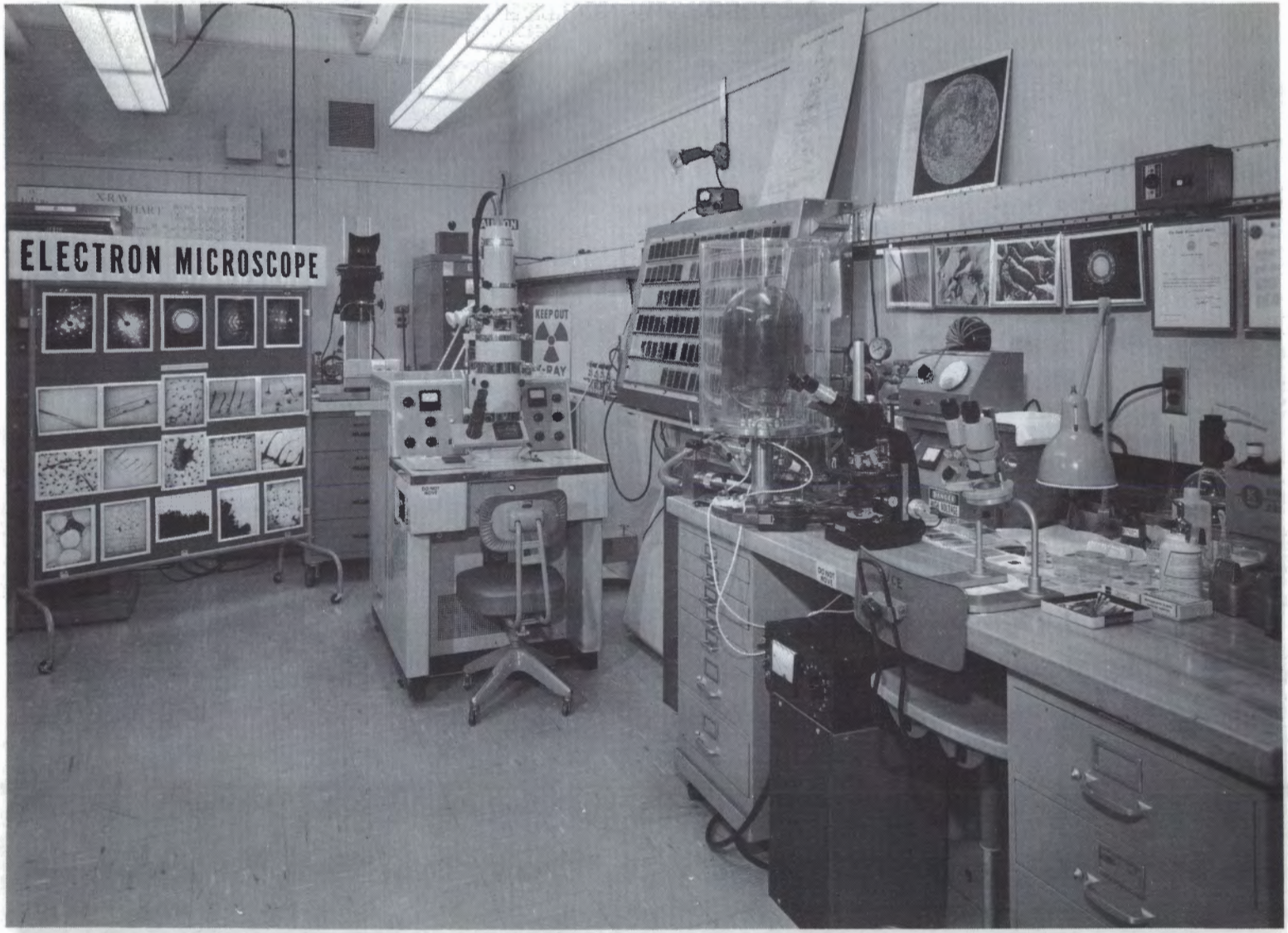
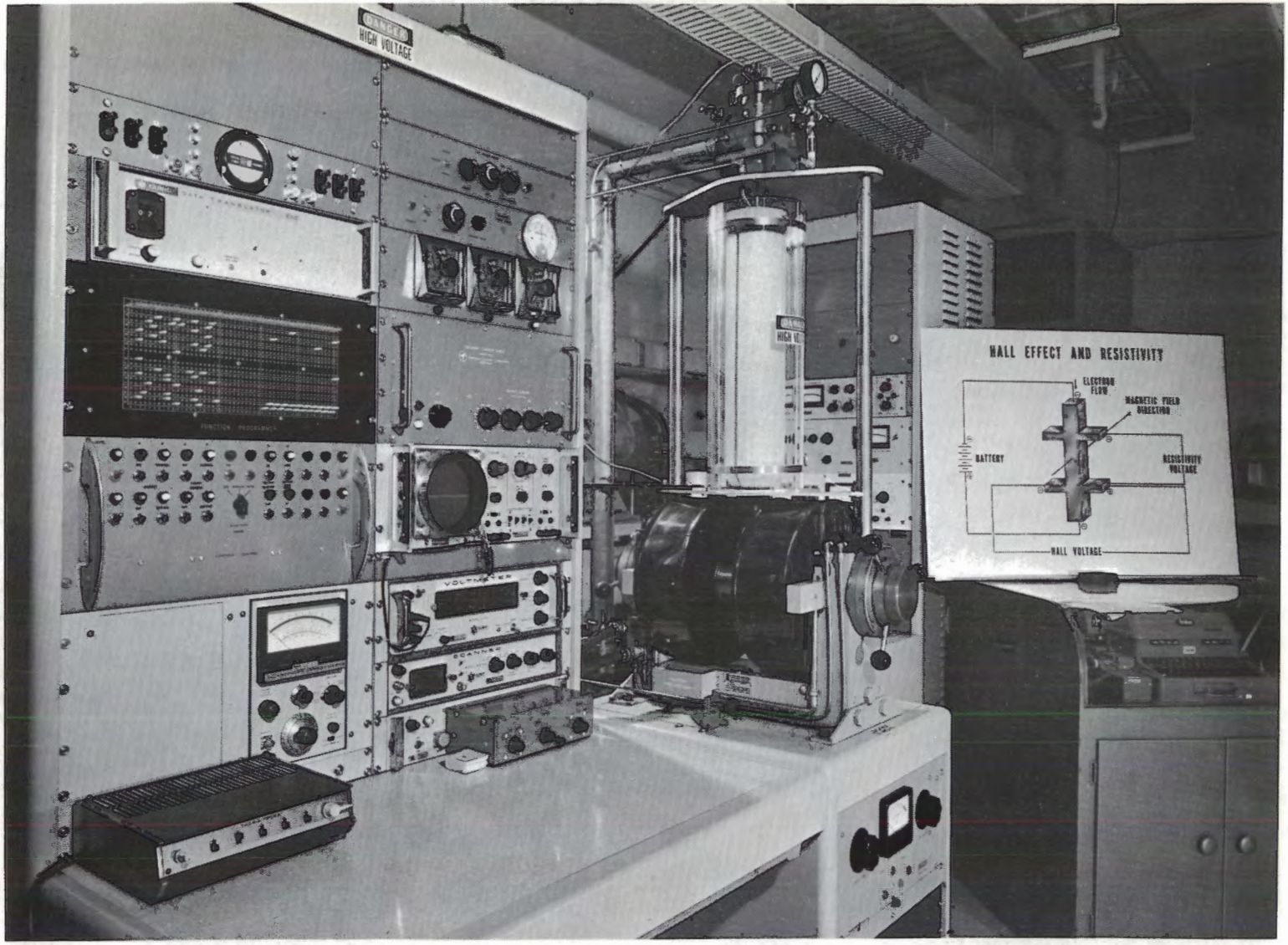
BASIC RESEARCH



ATOM REACTIONS

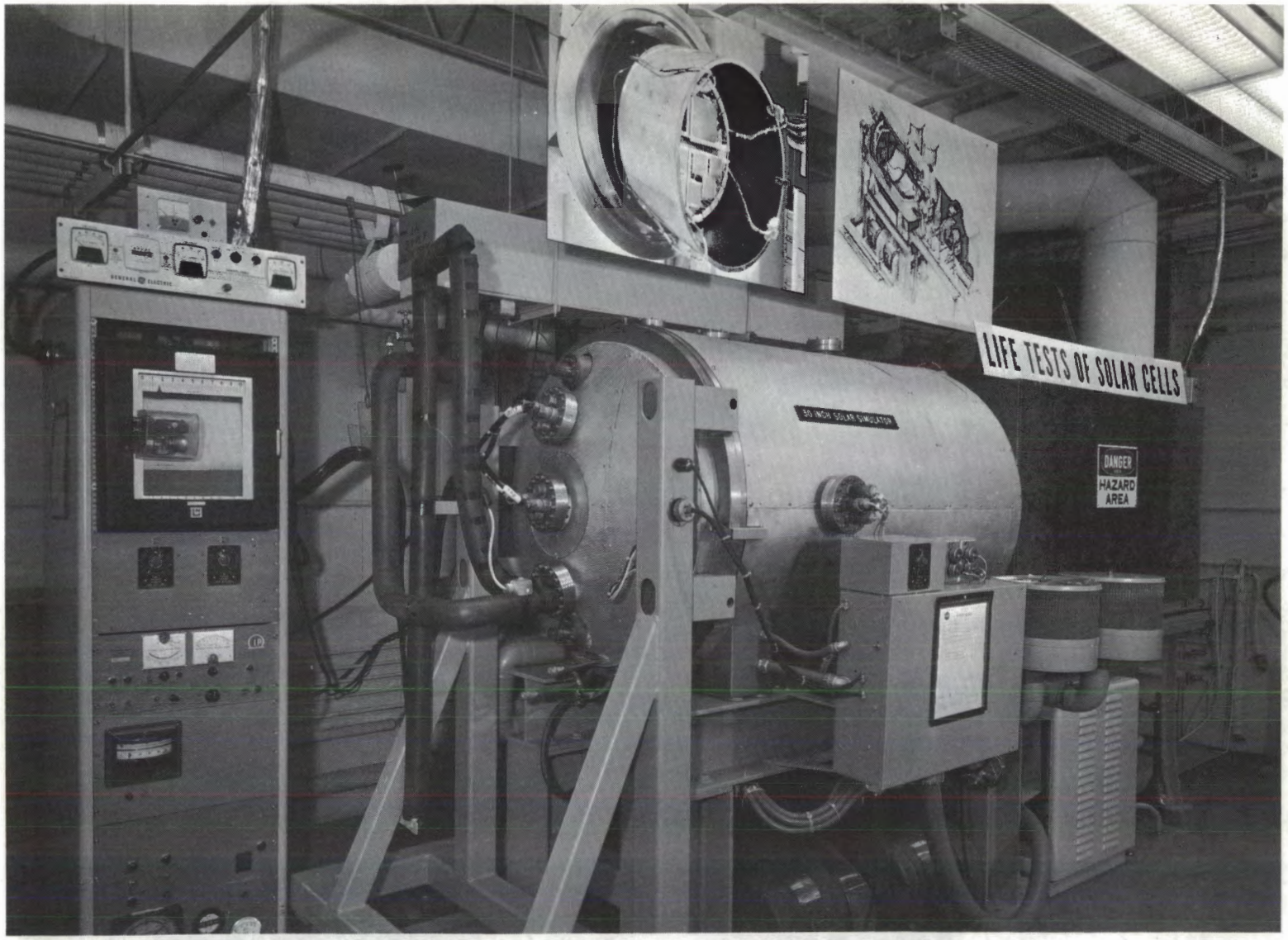


HALL EFFECT AND RESISTIVITY

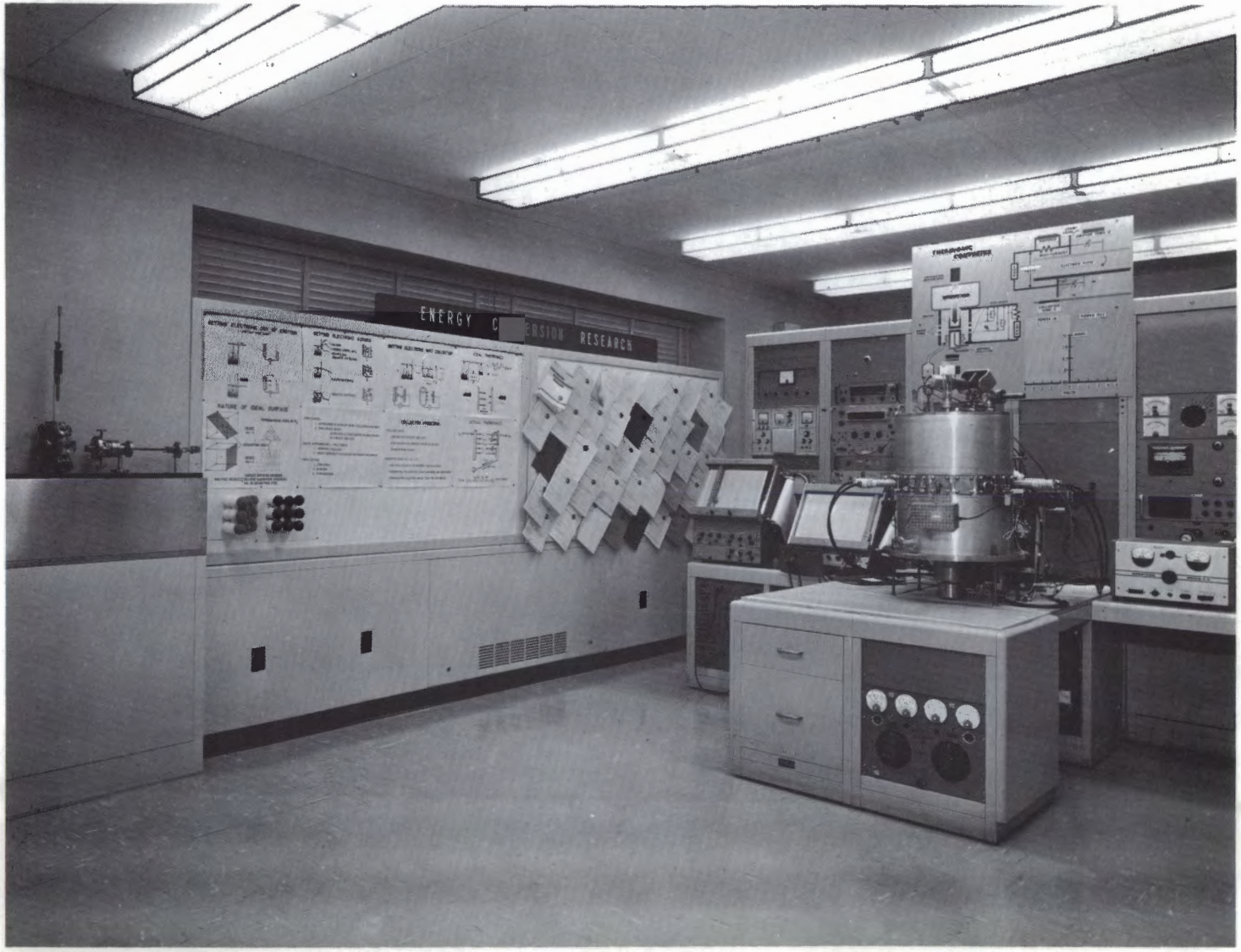


ELECTRON MICROSCOPY

LASER DIAGNOSTICS OF PLASMAS



LIFE TESTS OF SOLAR CELLS



THERMIONICS

BASIC RESEARCH

INTRODUCTION

Science is driven by the mainspring of curiosity. You have seen or will see today several examples of basic research work which are application oriented. A good deal of basic research work is also being done here at Lewis solely to satisfy this scientific curiosity. It is this type of basic research which I will discuss here today. The basic research areas under study here at Lewis include solid state physics, chemical kinetics, plasma and nuclear physics, and a number of others. I will discuss only one field, solid state physics, and I will discuss only one topic from solid state physics, the study of defects in crystalline solids.

Crystals are made up of regular arrays of atoms. This model illustrates an example of such an array. Most common everyday solids are crystalline; they are usually composed of many tiny crystals which can only be seen with special techniques. The particular geometric arrangement of the atoms in a crystal, and some of the properties of the crystal, are determined by the forces of attraction and repulsion between the atoms. However, many of the properties of crystalline solids are strongly dependent on imperfections in the regularity of this arrangement of atoms. Properties such as strength, ductility, and electrical conductivity can be drastically altered by crystalline imperfections. An example of this is that the strength of an actual sample is normally 100 to 1000 times less than it would be if it were a perfect crystal, that is, a crystal without any imperfections.

Some typical imperfections, which we call crystal lattice defects, are portrayed here (fig. 1). Here is a regular array of atoms in a crystal, each circle representing one atom. Here is a place where an atom should be and is not - a missing atom, which we call a vacancy - and here is a cluster of vacancies, which we call a void. Here is an atom where it should not be - in an improper or irregular

position in the crystal. We call this an interstitial atom. And, here is an impurity atom. An impurity can be in a proper crystal position as it is shown here, or in an interstitial position. The next slide (fig. 2) illustrates a dislocation. The dislocation is created by this extra plane of atoms (the shaded plane) extending part way through the crystal. Here is where the extra plane ends. You can see the dislocation right here where two planes are pushed apart to make room for the extra plane. Some of the larger defects can be seen with special microscopes, while the existence of others has been predicted theoretically and confirmed by appropriate experiment. Since defects play such an important role in the properties of solids, a detailed understanding of their structure and behavior is of prime concern to us. I will now describe three areas in our solid state physics program in which we attempt to characterize these things we call crystal defects and determined their relation to solid behavior.

The first approach is to try to observe defects directly. Within the past decade a device called the field ion microscope has been developed. It enables us to see individual atoms and, therefore, to study dislocations in atomic detail, as well as point defects such as vacancies and interstitials. On the field ion microscope screen, the defects are seen in much the same way as they were depicted in the slides. The field ion microscope images the atoms in the tip of a fine metal wire which has been electropolished to a supersharp point. In order to give you a feeling for the dimensions involved, we have prepared a series of three microphotographs, mounted here on the stage, of a typical specimen of tungsten wire, 0.004 inch in diameter, about twice the diameter of a human hair.

In the first photograph we see the specimen as imaged with a conventional high power optical microscope - magnification about 1000. Here we see the full diameter of the 0.004-inch wire and the entire tip. The second photograph is an electron micrograph - magnification about 1 million. Here, the field of view is a great deal smaller than here, so that only the tip of the specimen is

imaged. The third photograph is a field ion micrograph with a magnification of about 10 million. Here we are no longer looking at a side view or profile of the specimen, we are looking headlong at the point, just as I am looking headlong at this pointer. If we look again at the second photograph, we can see that the tip of the specimen is actually a hemisphere. To understand further what we see in the field ion microscope, let us consider this model of the tip. Each ball in the model represents one atom in the actual tip hemisphere. This model is an accurate representation of the crystal structure of the metal tungsten. Incidentally, if we were to make a model of the 0.004-inch wire to the same scale, it would be 3 miles in diameter.

The way in which the field ion microscope operates is as follows: Imagine that this pointer is the tungsten wire specimen and that the screen rises vertically at the front of the stage. The screen is a glass plate coated with a fluorescent material (like a TV picture tube) and also with a layer of conducting material, tin oxide. The screen forms one boundary of the evacuated specimen chamber. In operation, a high dc voltage (kilovolts) is applied between the specimen and the conducting coating on the screen.

A small quantity of helium gas is admitted to the sample chamber, some of which condenses on the specimen and some of this condensed helium becomes ionized.

Note that the tip is not smoothly hemispherical - it is really terraced, that is, made up of planes of atoms, with the edges of the planes of atoms forming a hemispherical shape. At the edges of the planes the radii of curvature are very small; hence, the electric fields are very large. In these regions, the helium ions are stripped off and accelerated through the electric field to the screen. The ions strike the fluorescent coating, causing the spots which we observe visually. So we see, that only certain atoms are imaged and seen. These are some of the atoms at the edges of the planes. To illustrate the edge atoms which are imaged, we have painted the corresponding balls in the model with fluorescent paint so that, with the

lights extinguished and the model illuminated with ultraviolet light, the protruding atoms stand out as bright spots. If we now compare the model with a field ion micrograph (fig. 3), we can see the close resemblance. Here is an enlargement of a portion of a field ion micrograph (fig. 4) on which you can see a dislocation just as it was depicted on the slide. The dislocation is right here in this area, and here are the two planes pushed aside to make room for the extra plane.

Our work at the Lewis Center with the field ion microscope is in two complementary parts. First, we are studying the defect structure of tungsten by analyzing photographs such as these. Second, we wish to improve the understanding of the imaging process itself, and thereby our ability to interpret the micrographs accurately. Note that in both slides the atoms are imaged as blurry spots. This blurring limits the resolution of the instrument and is caused by the vibration of the atoms in the tip. The vibration is greater at higher specimen temperatures. An improvement in resolution is desirable for both parts of our work and has been achieved here at Lewis by redesigning and modifying the microscope to operate at a lower specimen temperature: Thus, the vibration of the atoms is reduced, which reduces the spot size; the resolution is improved; and we are able to extract much more useful information from the micrographs. This micrograph (fig. 5) was made at an operating temperature of 21° above absolute zero. This micrograph (fig. 6) was made here with the improved microscope operating at 4° above absolute zero. Lowering the specimen temperature has indeed effected an improvement in resolution, as desired.

Let us now turn to a second area of research which deals with the understanding of crystal defects. This is the study of diffusion. Diffusion is simply the name we give to the movement of atoms through crystals. Diffusion is dependent on the presence of crystal defects. Diffusion is also of importance to many processes such as mechanical deformation, electrical conduction, and radiation damage. We are interested in the detailed mechanism of diffusion itself; we are also

interested in the effects on diffusion of external influences such as pressure, temperature, and strain. The next slide (fig. 7) shows two mechanisms by which an atom diffuses through a crystal. Here, we see an atom moving into a vacancy, leaving a vacancy behind. This process is called vacancy interchange. Here we see an atom moving from one interstitial position to another interstitial position. This is called the interstitial jump process.

Regardless of the specific mechanism of diffusion, the motion of a particular atom will not necessarily continue in a given direction. Diffusion can be described as a succession of independent jumps in random directions.

We have here a demonstration which uses lights to simulate the diffusion of atoms as a process of random jumping. Let us consider the possible motions of one atom, a single atom, which starts out in this position. We are constraining the atom to move only in the plane of the screen, and allowing only vertical and horizontal jumps. The atom could make its first jump to this position. It could equally well have jumped to any one of three other locations. If the atom had jumped to this position, it could make a second jump again to any one of four positions. Therefore, after the second jump, it could now be in any one of nine positions. Similarly, after the third jump, the atom could be in any one of 16 positions, and after the fourth jump, in any one of 25 positions. The intensity of the light at each location indicates the probability that the atom actually is in that location, and we see that the lights are brighter near the center, which means that it is more likely for the atom to stay near its starting point than to move off a great distance in a straight line.

If we start at the center with a continuous supply of atoms, then, after time is allowed for diffusion, the intensity indicates the relative number of atoms to be found in the various positions. As you might expect, we find more atoms at the center, near the source, than a great distance away.

In the laboratory, diffusion is more conveniently measured by placing two pieces of metal in contact with each other. Here, the interface is a plane rather than a point. The next display illustrates this situation where the atoms of one metal, represented by the lights, can diffuse into another metal, represented by the dark region. Notice the disappearance of the interface as the atoms of one metal diffuse into the other. In some of the work being done here, the rate of diffusion in iron is being measured by plating a radioactive isotope (radioisotope) of iron onto one end of an iron bar. Here the radioisotope is represented by the lights and the normal iron by the dark region. Diffusion of the radioisotope into the normal iron takes place for a measured length of time. Slices are then taken from the specimen, thusly, and by suitable counting techniques the relative concentration of the radioisotope is determined. From this, the diffusion rate can be calculated.

At this laboratory, our attention is focused on diffusion in the class of metals which includes most of the metals of importance for high-temperature structural applications. We have obtained information about the diffusion mechanism by measuring the degree of correlation between successive jumps. That is, the extent to which the direction of a jump depends on the direction of the preceding jump. These measurements, in the case of iron, are done by using two different radioisotopes of iron (Fe^{59} and Fe^{55}). These two radioisotopes are plated on the normal iron simultaneously, and the diffusion rate of each radioisotope is determined as mentioned previously. The difference between the rates helps to determine whether the diffusion is taking place by a vacancy interchange process, an interstitial jump process, or by some other process. This is particularly important in metals such as zirconium, titanium, and vanadium where some question exists as to the diffusion mechanism. Our measurements of the effect of pressure and temperature on diffusion have also helped clarify the diffusion mechanism in several metals we have studied.

Let me now discuss a third approach to the study of crystal de-

fects. This is the study of the effect of ionizing radiation on laser grade ruby. Solids have a characteristic color because of the way in which their atoms absorb visible light. For example, crystalline aluminum oxide is essentially colorless because it is transparent to visible light; that is, the aluminum and oxygen ions do not absorb visible light. If we add a small amount of chromium impurity to aluminum oxide, we obtain ruby. The chromium ion absorbs nearly all visible light except red, which is transmitted. Thus, ruby is red in color, as we all know.

The ruby laser is a device in which these chromium impurities can be made to absorb light energy of several wavelengths, that is several colors, and then be triggered to release all of this light energy in an intense burst of red light of a single wavelength. We have here a ruby laser with which I will demonstrate these principles. We have here a blue balloon inside a colorless one. The colorless balloon is transparent to visible light, including, of course, red. The blue one absorbs red light. Consequently, when I trigger the laser, in a few moments, the blue balloon will burst because of the high localized heating caused by absorption of the intense red laser light. At the same time the colorless balloon, which absorbs none of the light energy will remain intact. There will now be a loud bang. This brings to mind a medical application of the laser. Laser light is used to repair detached retinas. The light passes through the transparent lens of the eye unimpeded just as it passed through the colorless balloon. The laser light is absorbed by the retina, causing the retina to reattach.

In order to function as a laser, the chromium impurity in ruby must be an ion in the plus-three charge state. It is found that irradiation of ruby converts some of the chromium plus-three ion to the chromium plus-two state. This radiation can be nuclear reactor radiation, X-rays, or the type of radiation encountered in the Van Allen belt. Loss of the chromium plus-three ion is detrimental to laser operation. As a means of investigating the conversion process, we

employ the fact that each atom or ion in a crystal absorbs light of certain wavelengths; that is, of certain colors. We know that chromium plus three and chromium plus two have different absorption spectra. Thus, examination of the ruby's absorption spectrum before and after irradiation can indicate how much chromium plus three has been lost and how much chromium plus two has been formed. Here at Lewis we are using an absorption spectrophotometer in this work. This is an instrument which measures and records the intensity of light of various wavelengths (i. e., various colors) absorbed by the atoms in the crystal lattice. The instrument we have here will trace out the difference between intensity of light absorbed by a normal ruby crystal and one which we have irradiated in a beam of high energy X-rays. While this difference is being recorded, let me direct your attention to this chart which we made by recording separately the absorption spectra of normal unirradiated ruby, irradiated ruby, and pure aluminum oxide. This is the spectrum of aluminum oxide; it is an almost straight line indicating no absorption of visible light, that is, transparency as I mentioned previously. This curve is the absorption spectrum of normal unirradiated ruby. These two peaks occur because of the presence of chromium plus-three ions in ruby. This curve is the absorption spectrum for the irradiated ruby, and we see that the character of the curves is quite different.

While I have been talking, the spectrophotometer has been recording the difference between the absorption of the irradiated and the unirradiated specimens; that is, the difference between these two curves. From this curve, we can then determine what new species were formed by the irradiation. For example, this peak indicates the formation and presence of chromium plus two. In an actual experiment, we correlate this information with the total amount of radiation received by the ruby and with the resultant deterioration of the ruby's lasing ability. We are also interested in these results in connection with our studies of radiation damage ef-

fects on electrical conductivity in ceramic insulators.

In summary then, I have discussed examples of basic research in the field of solid state physics. An area of major concern in solid state is that of defects in crystalline solids and I have described three ways in which these defects are studied: by direct observation with the field ion microscope, by the study of diffusion, and by the use of absorption spectrophotometry.

ATOM REACTIONS

We would like to show you an entirely different basic research demonstration. The demonstration you just saw was all about solids. Here it will be about gases and how some of them react to each other.

You have all seen, in films or on television, gases roaring out the back end of a rocket. Chemical reactions of gases are important in rocket propulsion, and this is one of the principal reasons we do research in this area.

Now, let us have the demonstration. In this glass bell jar, ordinary oxygen is flowing. At the same time, we are evacuating the bell jar down to a low pressure. We will split ordinary oxygen (O_2) into oxygen atoms (O).

(Write equation on chalkboard.)

Oxygen molecules	Microwave discharge	Oxygen atoms
O_2	$\longrightarrow$	$O + O$

Presently, we are actively engaged in studying reactions involving oxygen atoms. Today's demonstration will illustrate a small, but

vital, part of the chemistry of atom reaction rates. Now let's make some oxygen atoms. That was easy enough. We used a microwave generator located here to supply the energy required to split some of the oxygen molecules into oxygen atoms.

But how do we know how many of the oxygen molecules were converted to atoms or even whether any atoms are actually flowing into the bell jar? You saw nothing in the bell jar before I switched on the atom generator and nothing afterwards. Both oxygen molecules and oxygen atoms are colorless. They are not conveniently pink and blue as I have them colored on the chalkboard. This fact not only complicates our demonstration but is a very real problem in our research with oxygen atoms and with other atoms as well. How do we measure atom concentration? Fortunately, for the specific case of oxygen atoms there are good methods of measurement. The rest of the demonstration will illustrate one such method.

The key to this method is that (1) nitrogen dioxide gas and oxygen atoms react to give off light

(Write equation on chalkboard.)

$$(1)\quad \text{Nitrogen dioxide} + \text{Oxygen atoms} \longrightarrow \text{Light}$$

and (2) no light is produced by nitrogen dioxide in contact with oxygen molecules.

(Write equation on chalkboard.)

$$(2)\quad \text{Nitrogen dioxide} + \text{Oxygen molecules} \longrightarrow \text{No light}$$

We turn on the nitrogen dioxide, and we see a light. To prove to any of you "Doubting Thomases" that the ordinary oxygen molecules will not also succeed in producing light we turn off the atom generator. No oxygen atoms, no light!

Therefore, we have just shown you that oxygen atoms are really present in the jar. Now let me indicate to you how we use this glow to measure the oxygen atom concentration.

Watch the bell jar closely, while I add the nitrogen dioxide gas to the system and slowly increase its flow rate. When I reach a particular nitrogen dioxide flow rate, we get a bright glow. If I were to repeat this procedure, I would always get the glow at the same value of nitrogen dioxide flow rate. If the oxygen atom concentration were to change, the point where the nitrogen dioxide glowed brightly would change accordingly. This is a good way to measure oxygen atom concentration.

I would now like to show you a nice variation of this method. Look at what happens when I add still more nitrogen dioxide. The flow is extinguished.

(Write equation on chalkboard.)

$$\text{Too much nitrogen dioxide} + \text{Oxygen atoms} \longrightarrow \text{No light}$$

So as I have written on the chalkboard, with too much nitrogen dioxide, there is no light. The flow rate of nitrogen dioxide at which the glow goes out is also quite reproducible. Therefore, either the point of maximum brightness or the extinction point could be used to measure oxygen atom concentration. The explanation of why these two phenomena occur and the details of the calculations of atom concentration are, unfortunately, too long a story to tell now.

If this were a real experiment, you would shut the flow of nitrogen dioxide off completely. It is no longer needed. The oxygen atom concentration has been measured. You would be ready to inject another gas into the bell jar for the purpose of studying its rate of reaction with oxygen atoms. At Lewis, reaction rates of oxygen atoms with ammonia and methane have recently been measured.

In the remaining few moments, I would like to finish the demonstration by showing you what happens when the nitrogen dioxide flow valve is shut off. You get your maximum brightness occurring once again. That is because, with the input of nitrogen dioxide cut off, the vacuum pump can suck out the excess nitrogen dioxide bringing it down to the concentration corresponding to maximum brightness.

ELECTRON MICROSCOPY

As you have heard, we are engaged in basic research in this building. On this floor we are particularly concerned with studies of the photovoltaic process. For us, these studies are divided into work with (1) the single-crystal silicon solar cell with which you are all familiar and which has proven itself in the NASA programs as a reliable source of space power, and (2) a new device, the cadmium sulfide thin-film solar cell.

The thin-film cell like the silicon solar cell is a semiconductor device but has quite different physical characteristics. It is thin, lightweight, and quite flexible.

(Show 3 by 3 in. cell and flex it.)

This device is composed of several layers making up a sandwich structure and is fabricated as follows: On a sheet of molybdenum foil a film of the compound semiconductor cadmium sulfide is deposited. This is accomplished by sublimation and condensation in a high vacuum chamber. This layer of cadmium sulfide is then coated with a layer of copper sulfide known as a barrier layer to give a so-called p-n junction photodevice. These two layers exhibit the photovoltaic effect; that is, upon exposure to sunlight, some of the energy of the light is absorbed and electrons are freed at the interface of the two layers. These electrons migrate to the surface of the copper sulfide and may be collected by a metal collecting mesh and made to

do useful work in an external electrical circuit before being returned to the molybdenum foil backing plate of the solar cell.

As each step in the fabrication of such cells involves precision in the control of the processes, it is necessary to know what is occurring at all times. Several analytical tools are used. One of these is the transmission electron microscope, which you see in this room.

On this board are mounted a number of photographs of surface studies made on cadmium sulfide solar cells during the different steps of the fabrication process. On some you can see the crystalline surface of the freshly deposited cadmium sulfide film. This particular film was several microns thick and, as you can see, has relatively large crystals growing in random directions. The formation of the barrier layer requires an etching of the cadmium sulfide surface. In several views, we see the effect of one experimental etching treatment which proved to be too harsh to produce useful cells.

To study surfaces with this type of electron microscope, with a range of magnification from about 600 to approximately 40 000, it is necessary to make a so-called thin-film replica. In effect, a duplicate of the surface is made, which reproduces the surface to be studied with a thin layer of material which is somewhat electron opaque. These replications are made at this specimen preparation table with the high vacuum evaporators which you see.

Because our work is basic research, we are concerned with the photovoltaic phenomenon itself as well as the structural organization of the atoms within the solar cell that gives us increased response and, thus, higher efficiencies. The electron microscope may be used in another way to perform such analyses. Tiny amounts of a material may be studied directly within the microscope, and the atomic arrangement discovered by the method of transmission electron diffraction. With the particular microscope which we have here, we also may examine larger samples of materials by bouncing electrons off the layers of atoms near the surface of a sample in a

process known as reflection diffraction. Some photographs showing such atomic patterns are shown on this display.

To show you the magnification range of an instrument of this type, we have prepared a number of photographs of a small section of a mosquito wing. The first photograph taken at a magnification of 2000 shows surface features which can barely be made out with the highest power light microscope. The subsequent photographs at progressively higher powers up through 120 000 bring out the features in ever increasing detail.

We thus have in the electron microscope a research tool of great value with which much information of value in our programs may be obtained.

HALL EFFECT AND RESISTIVITY

In our area of work, we are currently involved in measuring some of the basic electrical properties of semiconducting materials that are of special interest to the Lewis solar cell research program. The two fundamental measurements which yield the most information about the electrical characteristics of a material are the Hall effect and electrical resistivity. For the benefit of those who are not familiar with these measurements, I would like to illustrate the two effects with this chart. If we take a bridge-shaped sample of semiconducting material such as silicon or cadmium sulfide and pass an electric current (electron flow for the case illustrated) through the long axis of the sample, we can measure a voltage between two specified points along this same axis, which is known as the resistivity voltage. The magnitude of this voltage is simply a measure of how much resistance the material presents to current flow.

If the sample is then placed in a uniform magnetic field such that the direction of the field is perpendicular to that of the current

flow, as indicated by the arrow, the interaction of the magnetic field on the electrons will cause them initially to be swept to one side of the crystal, thus, setting up a transverse voltage that is perpendicular to both the current and magnetic axes. This voltage is known as the Hall voltage. By measuring the resistivity voltage, Hall voltage, sample current, magnetic field, probe spacings, and sample dimensions, we can calculate the electrical resistivity, the number of charge carriers, which, in this case, are electrons, that are available in the material for conduction, and the mobility of these charge carriers through the crystal.

An enlarged photograph of our sample holder is shown in figure 8. The actual size of the sample holder measures 2 inches in length by 1 inch in width. In the center of the holder there is mounted a typical single crystal sample of p-type silicon with its six electrical connections attached. On the top surface at each end of the sample we have also attached two thermocouples for measuring the temperature of the sample. With the sample mounting complete, the sample holder is then placed in the temperature control chamber, which is the vertical cylindrical Dewar system. The lower tip of this chamber extends between the pole pieces of the electromagnet located at the base of the Dewar system, where the magnetic field is applied to the sample. In this chamber, we can vary the sample temperature from 200^{o} to -450^{o} F.

The apparatus that is visible to the left and right of the temperature chamber - magnet assembly is an automatic data-collection system that is designed to automatically measure the Hall effect and resistivity over most of the temperature region previously described. The system is fully programmable, and, once the initial program is set up, it will operate unattended, thus, freeing the operator to perform other tasks, such as preparing additional samples and analyzing data. The automatic system can re-

cord data at a faster rate and with greater accuracy than is possible by manual methods.

The data are actually recorded by the Flexowriter, which is located below the chart at the right. The Flexowriter provides both a typewritten copy of the data and a punched paper tape that is suitable for computer processing. At the end of each data run, the punched tape is sent to the Lewis computing facility where the appropriate computer program is selected and the data are calculated automatically. The computer provides us with both tabulated results and machine plotted graphs. By this method the required calculation time per sample is reduced from 2 to 4 weeks of manhours down to 1 minute or less of actual computer run time.

LASER DIAGNOSTICS OF PLASMAS

In a previous demonstration, the operation of a ruby laser was observed. That laser, by its very nature, emits a pulsed beam of light of very short duration. Here, in this laboratory is an example of how a gas laser, which emits a continuous beam of very small diameter, can be used as a research tool.

This research is directed toward the better understanding of the physical phenomena occurring within a thermionic diode. A thermionic diode is a device which converts heat energy directly to electrical energy. It will be used for space applications in the future. The principle of its operation is to have a hot emitter of electrons (cathode) and a relatively cool collector of these electrons (anode) placed inside an evacuated container. The flow of electrons between these two surfaces generates a useable electric current. To facilitate the flow of these electrons, a plasma is generally formed between the two surfaces (fig. 9) by using, in this case, cesium vapor. This plasma consists of several types of particles, such as cesium atoms, cesium ions, and electrons. An ion is sim-

ply an atom which has had one of its electrons removed by some means such as the effect of the high temperature of the surroundings and/or atomic collisions in the vapor. The densities of these particles is of great interest, and the present state of the art is such that not many experimental data are available concerning them. This is where the gas laser interferometer becomes a useful tool.

As was mentioned previously, the gas laser generates a very slim, continuous beam of light. More important, however, is that this beam of light has, in effect, only one frequency. This fact is in contrast to ordinary light such as that which is emitted by an incandescent lamp. Ordinary light contains almost all the colors of the rainbow to some degree or another, and each color has a particular frequency associated with it. The unique feature of the laser is that it emits only one of these frequencies.

In this experiment, two helium-neon lasers are used. The frequency of each laser beam is inversely proportional to the length of the resonant cavity containing the helium-neon discharge tube. By placing the thermionic diode that contains the cesium plasma inside the resonant cavity of one of the lasers (fig. 9), the frequency of that laser is altered slightly because of the change in the optical length of the resonant cavity. (The optical length is a function of the index of refraction of the cesium plasma.) The frequency of the other laser is not, of course, affected by the cesium plasma. Hence, by combining the two laser beams (fig. 9), the difference in frequency between the two beams can be detected by an ordinary photocell and observed on an oscilloscope. Since the frequency difference is proportional to the various densities of electrons, atoms, and ions in the plasma, a direct observation is made of what is occurring within a thermionic diode.

LIFE TESTS OF SOLAR CELLS

Today most satellites, such as Telestar and weather satellites, depend on solar cells such as these silicon cells as their primary source of power. These cells must withstand a very hostile environment: electron and proton radiation, ultraviolet radiation in sunlight, large temperature changes, and an extremely good vacuum. When a satellite is in orbit, it spends about 60 minutes in sunlight and 30 minutes in the shadow of the earth. During one of these cycles, temperatures of the array vary about 270° F.

In this chamber we try to simulate such a cycle. Now, if we look at our phantom sketch (fig. 10), I'll try to show you what we have done to achieve this. Here is a 5-kilowatt tungsten-xenon lamp, which gives us the equivalent of sunlight with its high ultraviolet radiation. This reflector and these three special lenses focus the light through this 1-inch-thick quartz window to the rear of the chamber where the test plane is located. Along the walls of the vacuum chamber, as you can see here and here, are the liquid-nitrogen-cooled radiation shields. These shields are painted black and cooled down to 300° F below zero. This gives us the dark cold simulating outer space. The vacuum pumps located here on the floor and to the rear of the chamber give us our hard vacuum, equivalent to about 50 miles out into space. We do not simulate the electron and proton radiation because from previous tests the types of cell we are testing show various high radiation resistance. They have been irradiated for an equivalent of 10 years in space with practically no loss of power.

New types of cells such as these lightweight, flexible, thin-film cells (these cells were discussed at the space power stationary systems lecture) are at this time being tested in the chamber. They are suspended on wires so that this side faces the light and the back faces the dark, cold radiation shields similar to outer space. During the light-on part of the cycle, we record, on this recorder, the

efficiency and the operating temperature. During the light-off part of the cycle, we record only their temperature. We find these cells vary from 120° to 150° F below zero. Early cells failed rapidly, some in just a few cycles. They failed in many ways: plastics turned brown, cell delaminated and blew up like this one, and some even cut their way out of the plastics. By studying these failures, we now have cells such as these which have gone more than 20 000 cycles with practically no loss of power or physical damage. I think you can see how important this experiment is for evaluating new types of cells not yet used in space.

THERMIONICS

You have been exposed, or you will be exposed, to the operation and the nuclear application of thermionic converters. Here, we are concerned with the physics involved in the converter. In the short time we have, I will attempt to acquaint you with the experiment being conducted in this room.

Tests have indicated that high electron emission can be obtained by depositing low work function materials on certain crystal planes of refractory metals. We know that the work function of a material depends on the crystal face exposed and can be greatly changed by even a small amount of adsorbed foreign atoms. Some surfaces appear to be more desirable than others for adsorbing and retaining low work function materials. For example, in a body-centered-cubic crystal, a 100 Miller index plane appears to be more desirable. By investigating the effect of adsorbed material on the electron emission from the various crystal faces, we hope to obtain information that will permit us to control the electrical performance of converters.

In this experiment, we are determining the emission characteristics of various crystal faces of refractory metals. Contained

inside this vacuum belljar is a research thermionic converter which is similar to the unit shown in this exploded display. This center-body houses the emitter and collector assembly and provides entry ports for the apparatus required to monitor the experiment. The emitter and collector are surrounded by guard rings. The surfaces are heated by electron bombardment from an electron gun. The surface in the experimental apparatus was prepared prior to this test by heating it to a very high temperature and pumping the test chamber to a vacuum of the order of 10^{-11} atmosphere. This operation removes contaminants from the surfaces of the test specimen. These contaminants are identified by observing the trace obtained on the x-y plotter from the mass spectrometer. The electrical performance of the converter is recorded on this x-y plotter. Work functions of the emitter and collector will be obtained from this information for clean surfaces and for those surfaces containing adsorbed atoms.

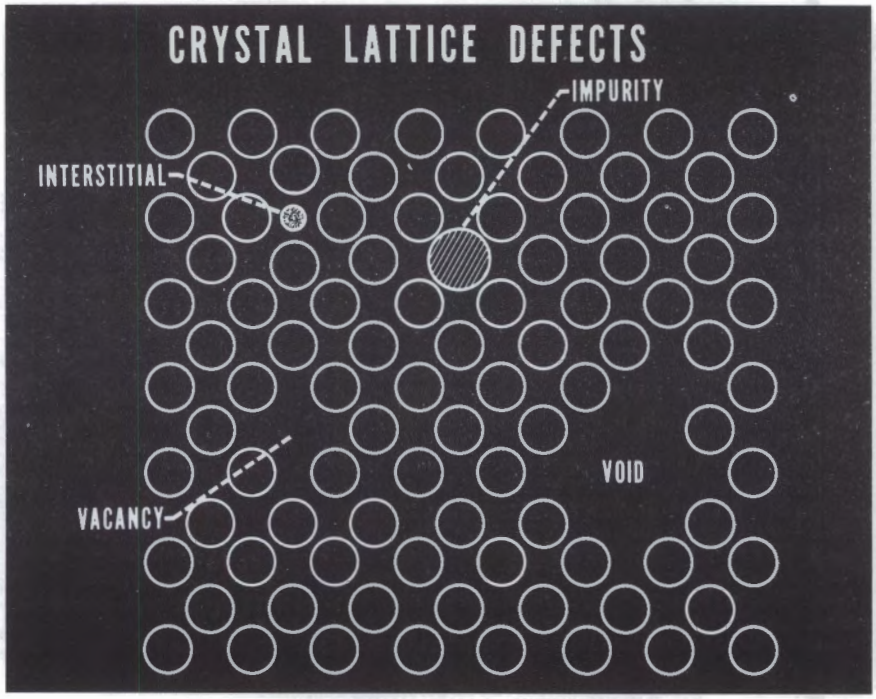


Figure 1

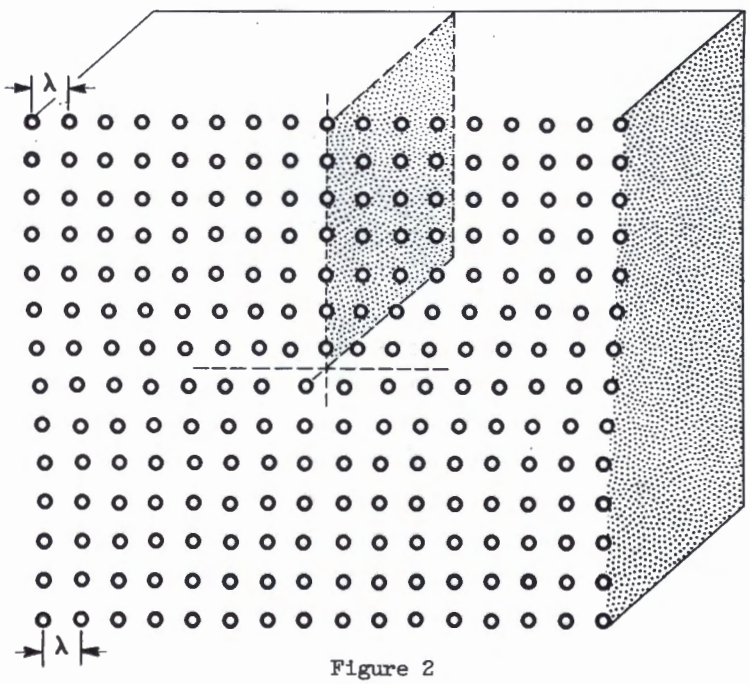


Figure 2

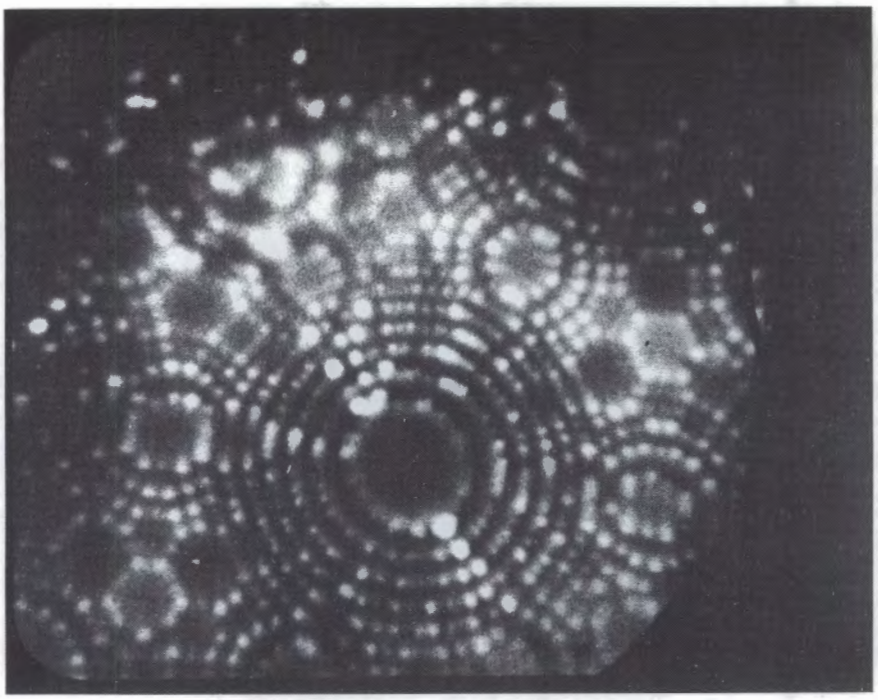


Figure 3

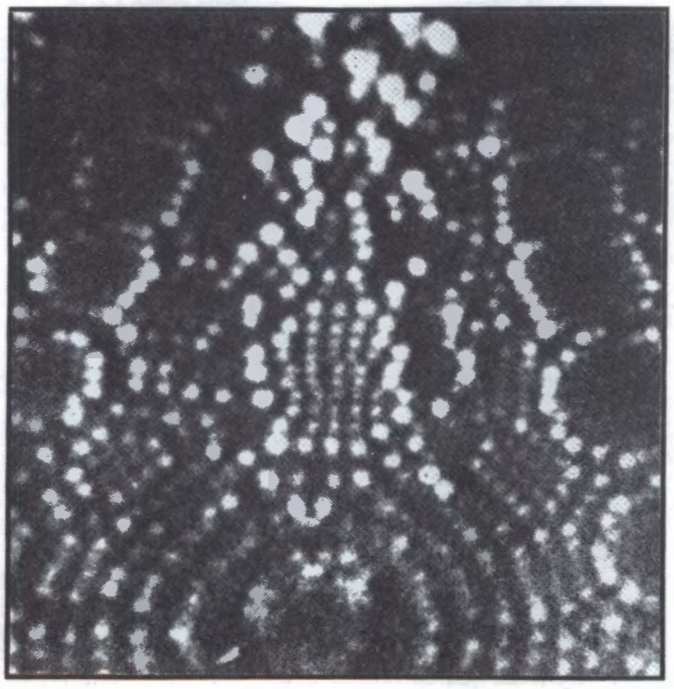


Figure 4

Figure 5

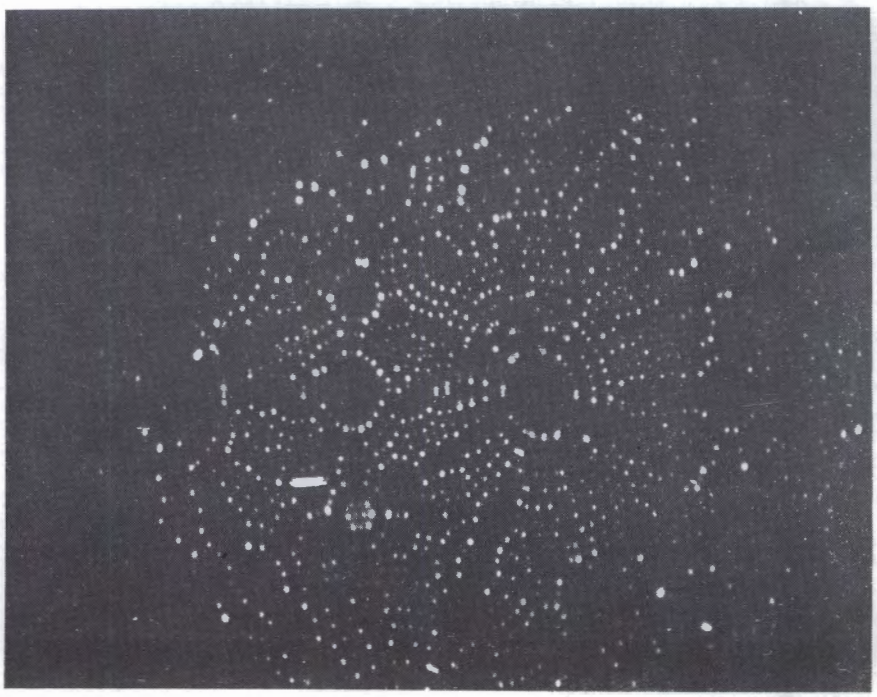


Figure 6

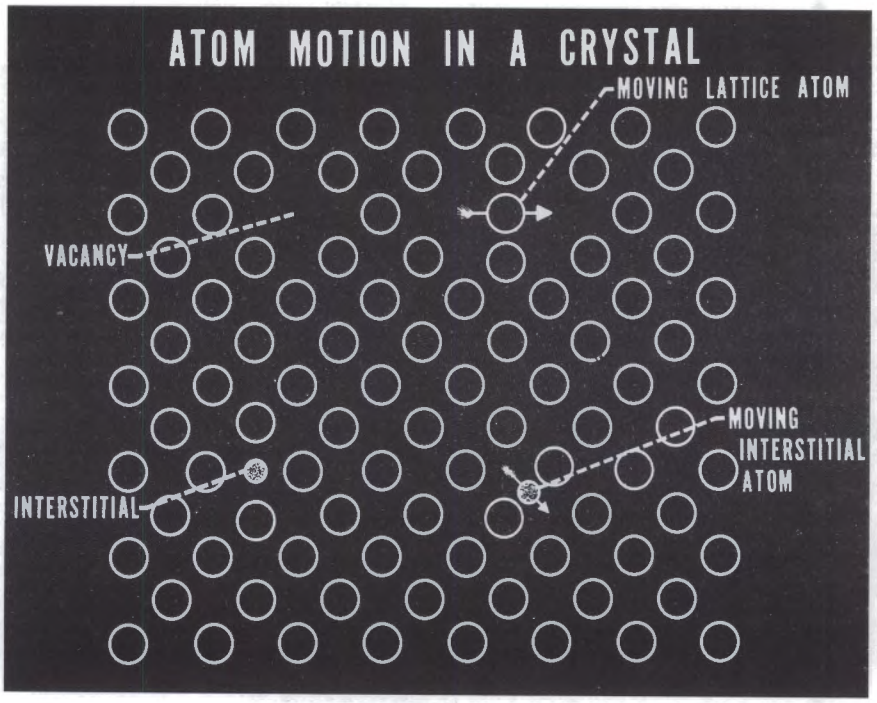


Figure 7

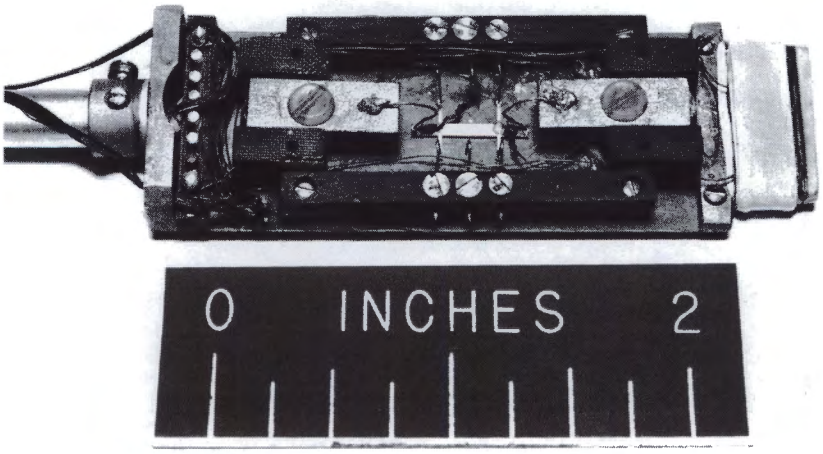


Figure 8

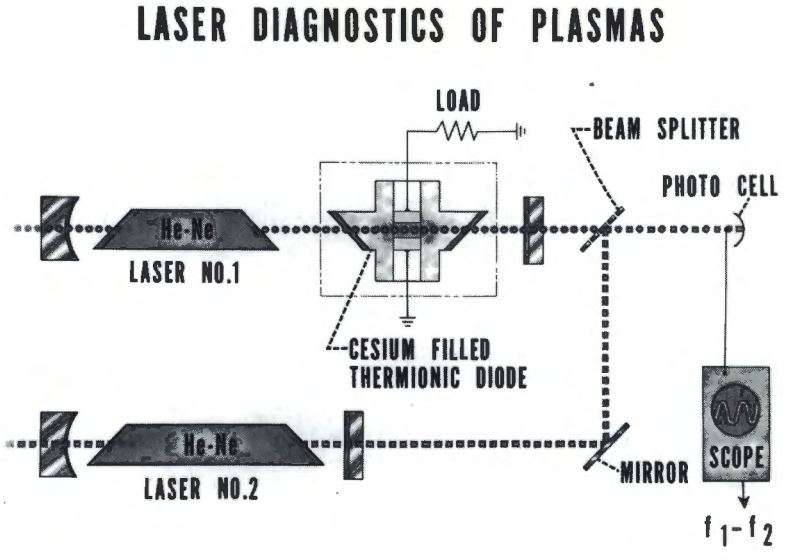


Figure 9

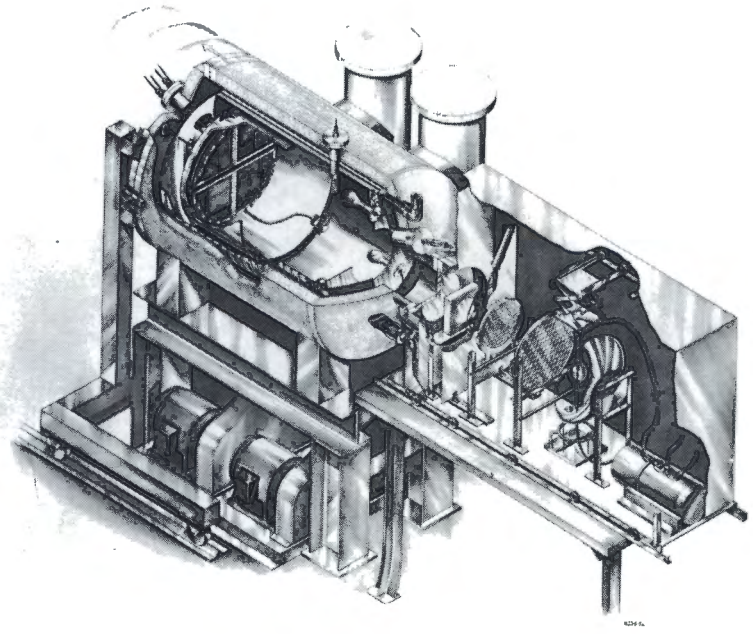


Figure 10

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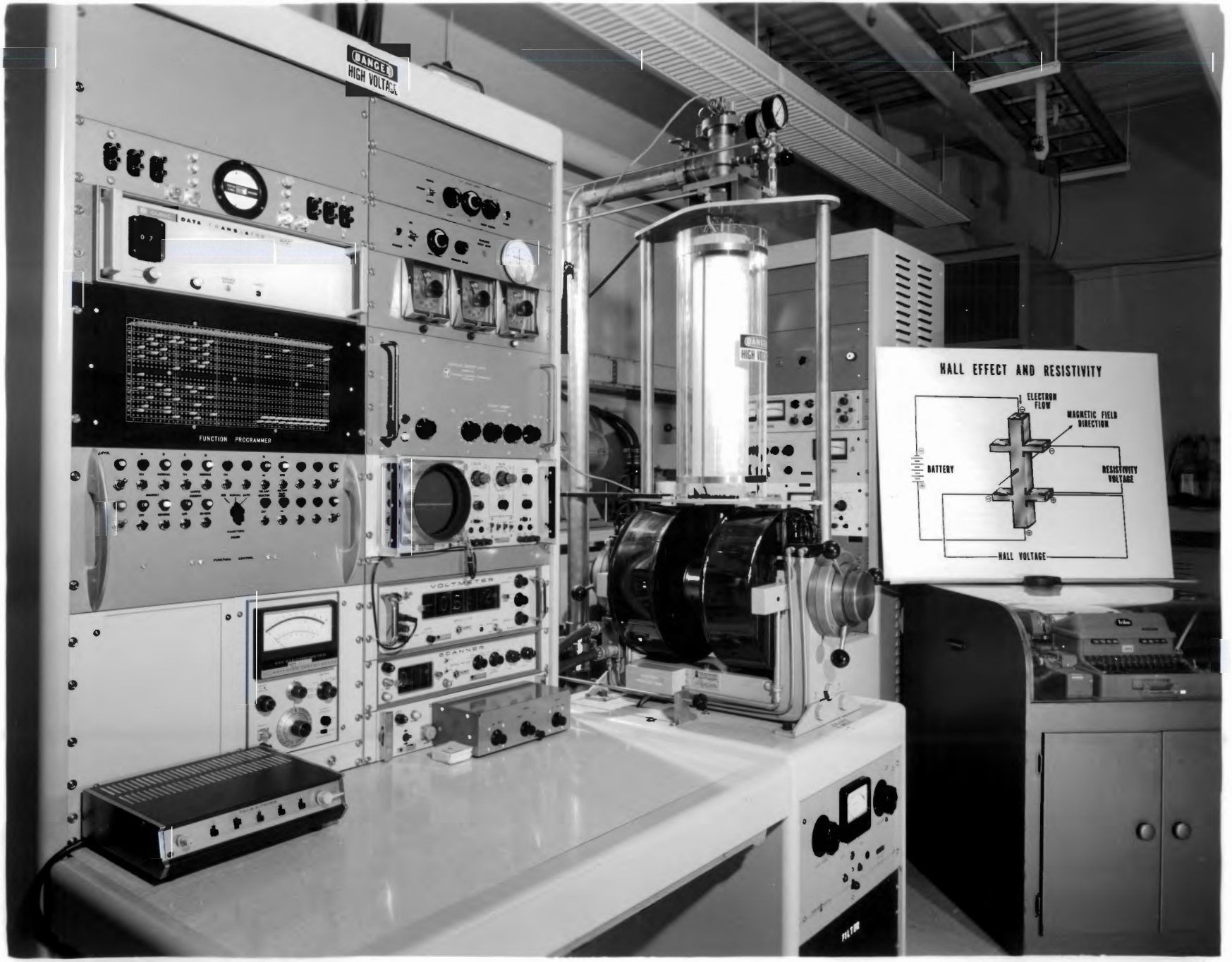

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