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The Role of the Physicist in the Automotive Industry

By Gerald M. Rassweiler

PHYSICS has been described as the science of matter and energy. Looking at this in slightly different but analogous terms, the definition encompasses the principal interests of the automotive industry, namely materials and power. As shown in Table I this industry uses very sizable percentages of

Table I. Materials

Percent of Total US Consumption Used by the Auto Industry

Steel (all forms)	19%
Copper	8%
Lead	44%
Zinc	35%
Aluminum	8%
Nickel	15%
Rubber	62%

Source: AMA Facts & Figures, 1957, 1958.

our total US consumption of certain materials. The materials in this list are chiefly metals but the list could be expanded to include a variety of others such as plastics, glass, and textiles. These materials in the hands of our customers are required to withstand severe mechanical vibration and impact together with a gamut of environmental conditions such as extremes of temperature, dirt, rain, ice, and snow. Thus the materials must be continually improved so that they can meet this service with ever-increasing reliability.

Turning our attention to power, Table II shows the total horsepower capacity of automotive engines in use

Table II. Distribution of Civilian Horsepower Capacity of the United States, Mid-1958

	<i>Millions of Horsepower</i>	<i>% of Total Capacity</i>
Automobiles, trucks, and buses	10 051	93.3
Railroad locomotives	65	0.6
Marine power	75	0.7
Aircraft (civilian)	24	0.2
Public utility central stations	173	1.6
Industrial power plants	23	0.2
Agriculture	230	2.1
Other	135	1.3
Total	10 776	100.0

in the United States. Domestically produced cars, trucks, and buses account for about 93 percent of all civilian power capacity. It is interesting to compare this with the power capacity of all public utility central stations which, though very large, represents only 1.6 percent. Each automobile power plant is an energy conversion system where the conversion must be accurately and easily controlled. The energy is used in a variety of ways, such as cooling, heating, steering, and braking, in addition to propelling the car; the number of these uses continues to increase.

Thus, it is apparent that the automotive industry with its vital interest in materials and power provides a fertile field for the application of physics.

Let us consider more specifically what physicists are

doing in the automotive industry. When I joined the Laboratories of General Motors in 1928 my supervisor, Dr. E. J. Martin, told me that he spent a good share of his time teaching "sophomore physics" to engineers. Up to that time he was the only physicist in General Motors and it is not surprising that his consulting services were much in demand. But other physicists and other activities were on the way. Ten years later, the American Physical Society held a symposium at the University of Michigan on physics in the automotive industry. Some of the subjects discussed are shown in Table III. These subjects are still of interest to our industry. However, as might be expected, many

Table III

Some Papers from an APS Symposium, "Physics in the Automotive Industry", 1938 (J. Appl. Phys., 1938)

- Introduction. Physics and the Automotive Industry—F. K. Richtmyer.
- Contribution of the Physicist to Highway Illumination—C. G. Found.
- Studying Engine Combustion by Physical Methods—L. L. Withrow and G. M. Rassweiler.
- Mobility Method of Computing the Vibration of Linear Mechanical and Acoustical Systems: Mechanical Electrical Analogies—A. F. Firestone.
- Scientific Training and Its Relation to Industrial Problems—C. F. Kettering.
- Human Beings and the Motor Car—Carl Breer.
- Physics of Rubber as Related to the Automobile—W. F. Busse.
- Some Physical Problems of Noise Measurement—Paul Huber.
- Photoelastic Analysis Practically Applied to Design Problems—O. J. Horger.

Table IV. Problem Solving

Typical Areas of Activity of Physicists in the Automotive Industry

- Noise measurement and suppression
- Research instrumentation
- Air flow measurements and control
- Engine development
- Materials analysis methods
- Manufacturing process control
- Metal bonding
- Residual stresses
- Metal structure and properties
- Vehicle driver aids

Table V. Introduction and Industrial Exploitation of New Physics Techniques

Typical Areas of Activity of Physicists in the Automotive Industry

- Radiography
- Spectrochemical analysis
- X-ray diffraction
- Infrared spectroscopy
- Ultrasonics
- Electron microscopy
- Electron diffraction
- Radioactive isotopes
- Mass spectroscopy
- Nuclear magnetic resonance

Table VI. Research in Fields of Interest to the Automotive Industry

Typical Areas of Activity of Physicists in the Automotive Industry

- Ignition phenomena
- Combustion*
- Friction
- Magnetism
- Fluid physics
- Metal physics*
- Energy conversion and storage
- Corrosion*
- Traffic dynamics
- Magnetic materials
- Diffusion in solids*
- Semiconductors*
- Radioisotopes*
- Solid-state circuit elements
- Crystal growth
- Polymer structures

Note: An example of each of the starred items will be found in the text.

of the problems which concerned the physicist twenty years ago now lie in areas of engineering and other technologies and the physicists have moved into new activities.

Some illustrative subjects of past and present interest to physicists in the automotive industry are listed in Tables IV, V, and VI. In each Table the items are arranged somewhat according to the order in which the physicists became interested in them. The Tables represent three areas of responsibility of the physicists: problem solving, introduction of new techniques, and research. The three areas not only overlap but are closely related in a cyclic way. Chronologically, problem solving (Table IV), was the earliest activity of physicists in our industry, as it was in many others. In order to make unique contributions to this work the physicists brought into the laboratories the techniques and equipment of their profession, such as spectroscopy and x-ray diffraction (Table V). They were able to show that these tools were not only important in the laboratory, but had many industrial uses as well. Thus in due time some of the techniques were introduced into technological groups and into manufacturing plants. In the meantime, physicists with such working tools at their disposal began to devote increasing time to forward-looking research (Table VI). As their skill and knowledge increased they became more effective members of problem-solving teams. So each of these activities continues to grow and each supports and stimulates the others.

A few remarks on each of these three activities are in order.

Problem Solving

ASSISTING teams in the solution of problems associated with production or processing is a very interesting and profitable activity for the physicist. This may involve anything from a day's consultation to years of applied research and development. The nature of these problems can readily be inferred from Table IV but one example might illustrate how the

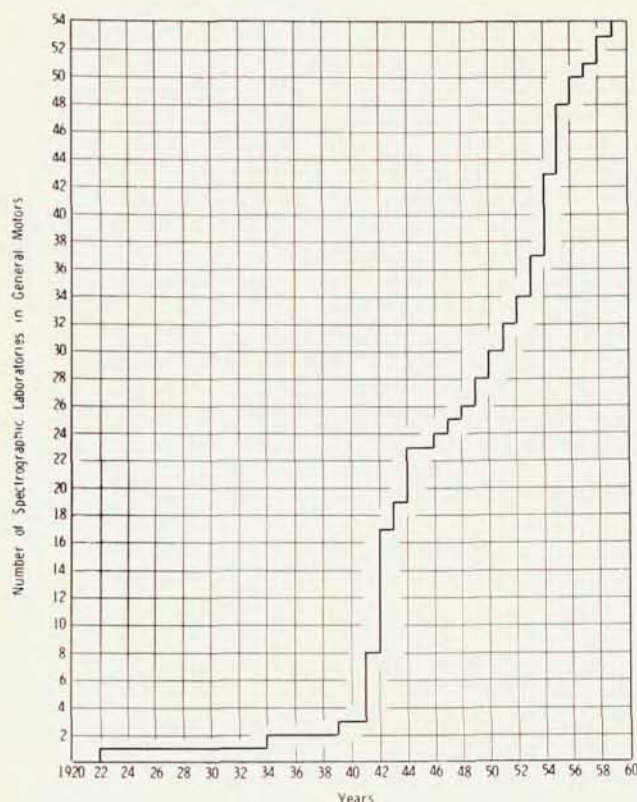


Fig. 1. The growth of spectroscopy in General Motors (Fry).

physicist can make unique contributions to industry problems.

A manufacturing problem of long standing is rapid "stock sorting". Perhaps a batch of several thousand finished piston pins includes some which have inadvertently been made of the wrong type of steel. They must all be scrapped unless they can be sorted to find those which are not within material specifications. As every physicist knows, the thermoelectric power of a couple is very sensitive to small changes in composition. This is, indeed, a great nuisance to those who measure temperature with thermocouples. But a physicist suggested that this sensitivity to composition be utilized to make a stock sorter. The idea was incorporated in an instrument with a hot and cold probe which, when

pressed against the parts, easily detected differences in composition.¹ Because it was rapid, nondestructive, and easy to operate it proved of great value. Physicists are successfully applying their methods of thought and experiment to many problems of greater and less complexity.

Introduction of New Physics Techniques

THE examples in Table V are listed generally in chronological order of introduction into automotive physics laboratories. The possibilities of introducing industrial radiography and spectrochemical analysis into manufacturing plants were being seriously studied as early as the 1920's. It is of interest to examine the growth of spectrochemical analysis because its continually expanding use can now be traced over so many years, as shown in Fig. 1.² There is a long, flat portion of the curve when spectrographs were used only in the Research Laboratories. Some of this lag time between laboratory and plant acceptance is unavoidable because it is necessary to develop methods and equipment suitable for plant use and to demonstrate their value to possible users. During this period the physicist must exercise perseverance, patience, and interest. It is also well for him to have a feel for psychology and economics and to appreciate the serious problems associated with introducing radically new methods into manufacturing plants. However, the eventual payoff which results from widespread acceptance of an applicable technique may be very great and this can certainly be demonstrated in the case of spectrochemical analysis.

It is obviously undesirable to have time lags of 15 or 20 years, as in Fig. 1, and efforts are being made to reduce them. For example, the industry is now introducing radioisotope techniques into its laboratories and plants. To expedite this process, the General Motors Institute and the Research Laboratories are presenting a ten-week training course in radioisotopes.³ The students are men with production know-how drawn from our manufacturing divisions. The physicists and others involved in presenting this course have found this a challenging experiment in industrial education. The flow of information has by no means been unidirectional because the contact with these production people has stimulated the scientists and has given them a realistic concept of plant problems. It appears that this sort

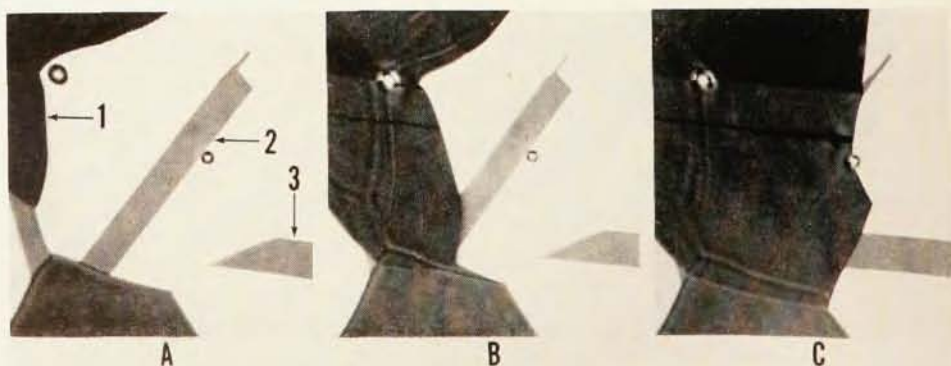


Fig. 2. Recrystallization of austenite as observed with an emission electron microscope (Rouze and Grube).

of effort by laboratories and plants can greatly accelerate the introduction of new industrial physics applications.

Research of Interest to Automotive Industry

DURING the 1930's, steady progress was made in the introduction of research aspects of physics into the industry. Neither physics nor research had the broad industrial acceptance then that they have now. The question was often asked, "How will this work help us build better cars next year?" After World War II the earlier research did indeed help to build better cars. The prewar research, in which physicists and chemists played a large part, built understanding of relationships between fuel-composition and knock, between engine-combustion-phenomena and pressure-development, between combustion-pressure, crankshaft-deflections, and "engine-roughness". This understanding made possible the development of high-compression engines soon after the war. The improved engine efficiency allowed the industry to reach the modern high standards of motor car performance which users now take for granted.

Some of the most important contributions by physicists will continue to be in research, both basic and applied. The interests of the automotive industry are so diversified that research in many fields can be supported. Table VI lists a few such fields.

Rather than discuss this research in general terms it might be more interesting to mention a number of specific research problems. The following illustrations are drawn from the General Motors Research Laboratories. Perhaps my friends from other automotive concerns will pardon me for limiting these examples to work with which I am familiar. Each Figure, 2 through 7, represents a forward step in a research project and will be described briefly under one of the general headings in Table VI.

Metal Physics (Fig. 2). Steel is obviously of great importance to the automotive industry. Most observations of microstructure are made at room temperature and changes at high temperatures are deduced from these observations. Phase transformations and recrystallization processes are now being studied directly at high temperatures with a thermionic emission electron microscope in which the image is formed by electrons emitted from the surface of the sample. The figure shows three pictures selected from a sequence taken during recrystallization of austenite at about 2000°F in SAE 1095 steel.⁴ This particular sequence shows some interesting twin band behavior. Twin band 2 recedes and nearly vanishes as the grain boundary approaches from the left. Twin band 1 is propagated with the advancing boundary. Twin band 3 breaks across an old boundary, where it has been pinned, to meet the advancing grain growth. Other new observations are being made with this technique. Quantitative measurements of rates and orientation will be added to these studies which are still in an exploratory phase. It is anticipated that increased understanding of the response of metals to high-temperature treatments will result.

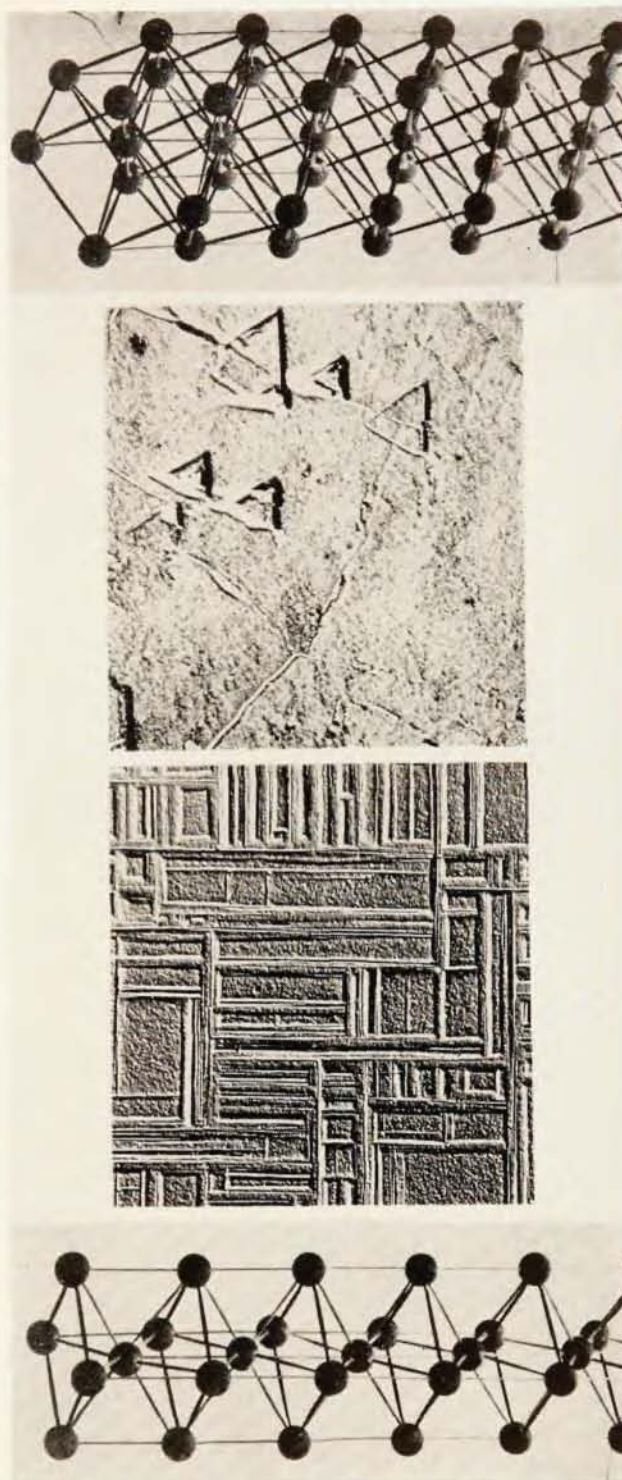


Fig. 3. Epitaxial oxide formation on single-crystal iron whiskers (Laukonis and Coleman).

Corrosion (Fig. 3). The figure shows electron micrographs of very thin oxide formations on {100} surfaces (bottom) and on {110} surfaces (top) of single-crystal iron whiskers. The topography of the oxide shows definite dependence on the underlying iron lattice which presents square or triangular arrays of atoms depending

on the crystal habit of the whisker. It is of interest that these epitaxial oxidation layers are obtained only under very special conditions involving very clean surfaces and short oxidation times at elevated temperatures. Observations such as these show that single-crystal iron whiskers are a good starting material for a fundamental study of oxidation.⁵ The ultimate objective is to study mechanisms, particularly the effect of crystal defects, during the early stages of the reaction.

Combustion (Fig. 4). Incomplete combustion reduces engine efficiency and releases, into the atmosphere, hydrocarbons which may be a factor in smog formation. Studies⁶ showed that exhaust gas hydrocarbon concentrations were highest under decelerating conditions (high intake-manifold vacuum). High-speed moving pictures through a transparent engine head revealed that in some explosions under these conditions a large portion of the charge did not inflame (upper right). This was subsequently found to be caused by dilution

of the combustible mixture with burned gas. As the throttle was moved toward the open position (moving left along the curve) the flame was able to propagate through larger portions of the charge until relatively complete inflammation was observed (upper left). Later studies⁷ have shown that a thin layer of gas at the chamber walls remains unburned even at full throttle, which explains why the curve does not fall to zero. This work has suggested several means for decreasing exhaust hydrocarbons. But much more basic information is needed on combustion, on practical corrective means, and on the relation, if any, between exhaust hydrocarbons and smog.

Diffusion in Solids (Fig. 5). The presence of gases in metals, and particularly hydrogen in steel, is known to cause detrimental metallurgical effects such as delayed brittle fracture. As a part of the investigation of the mechanisms involved, the mobilities of gas atoms in metal lattices are being measured using a sensitive

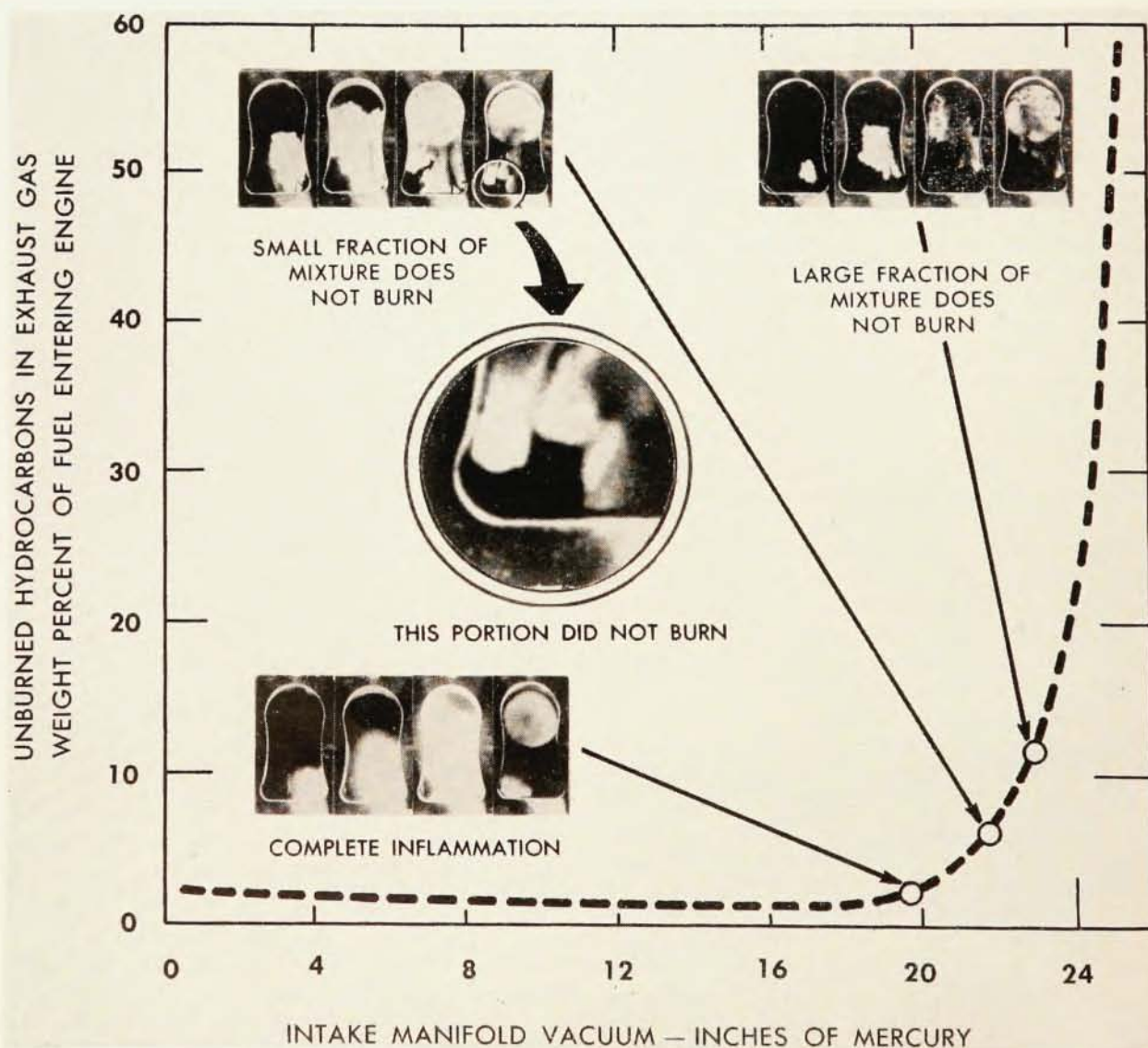


Fig. 4. Studies of incomplete combustion in an engine (Wentworth and Daniel).

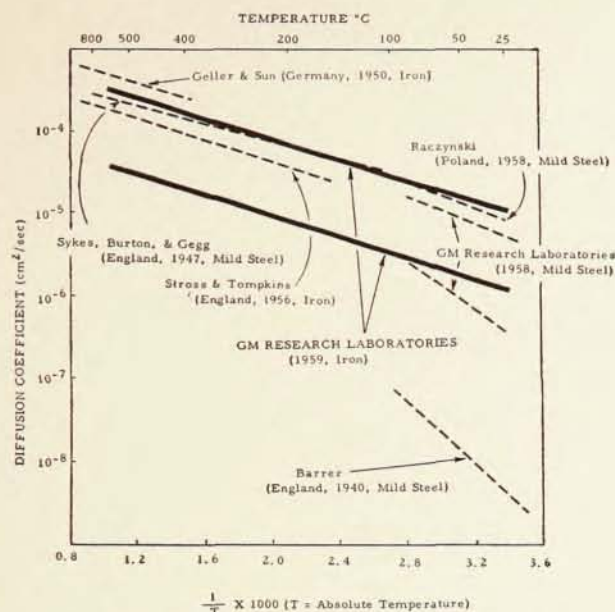


Fig. 5. Hydrogen diffusion coefficients in iron and mild steel (Frank, Swets, Lee, and Fry).

mass spectrometer to monitor gas evolution.⁸ The figure is a composite of the temperature-dependent diffusion coefficient observations for hydrogen in iron and mild steel. Published data are shown as broken lines. Data at "room temperatures", which are difficult to obtain, were meager prior to 1958 and these early data were shown to be low by recent work. The results of our present investigation over the temperature range from 25 to 700°C, as shown by solid lines, indicate the possibility of two diffusion coefficients at each temperature which are considered to be associated with two processes. It is of theoretical interest that these results on hydrogen diffusion in steel are not consistent with simple interstitial models for diffusion which appear adequate in many other systems. It is of practical interest that the new values for diffusion coefficients at room temperature can be associated quantitatively with the times involved in delayed brittle fracture.⁹

Radioisotopes (Fig. 6). Many radioisotopes which have high potential industrial uses are not commercially available and their characteristics are not accurately known. The figure illustrates a development project on Samarium-145.¹⁰ A low-energy photon-emitting radioisotope is required to extend radiography and thickness gauging to thinner specimens. Sm^{145} was produced by reactor irradiation of enriched Sm^{144} in oxide form. The 38.6 kev peak was found to be even more prominent than expected from published data, making the isotope an excellent low-energy source which is nearly "monochromatic". A method of fabricating the oxide into a solid pellet and the study of attenuating effects of source and holder were important parts of the project. Both medical and industrial uses are developing for this and other new radioisotope sources which are coming out of this work.

Semiconductors (Fig. 7). Research in semiconductors

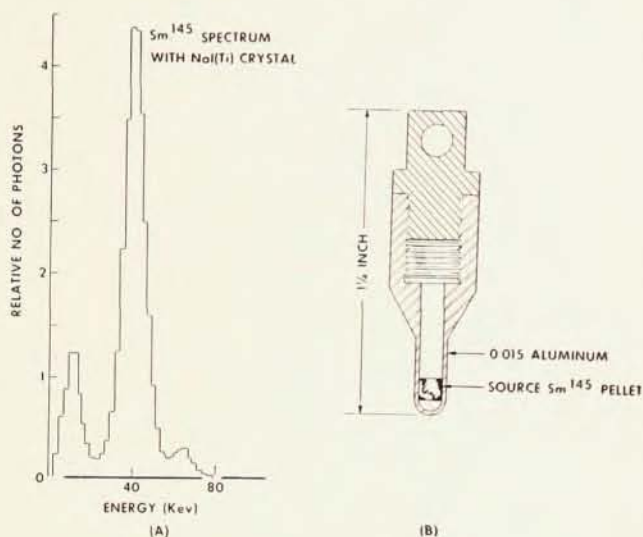


Fig. 6. A new low-energy radioisotope source, Sm^{145} (Green and Cheek).

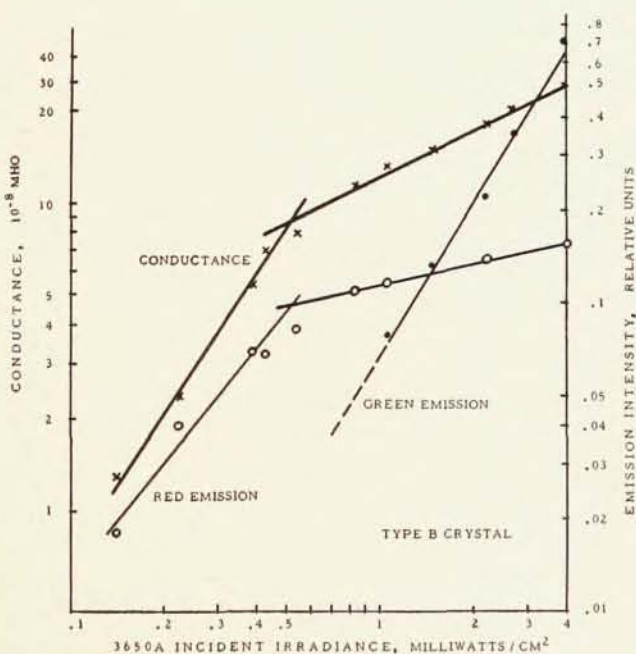


Fig. 7. Fluorescence effects in a cadmium sulfide crystal (Vuylsteke and Sihvonen).

esting break in the curve. There is a simultaneous change in the slope of the conductance curve and the crystals start to show green luminescence. This behavior is adequately explained in terms of trapping by sulphur vacancies. Thus some progress is made in understanding the important effects of departure from stoichiometry on the luminescent and electrical properties of this semiconductor.

It is apparent from the above examples that the interests of the automotive physicists are turning in the direction of more basic research. It becomes even harder to answer the old question, "How will this work help us build better cars next year?" But then the question is asked less frequently now than twenty-five years ago. It is expected that in the research phases of their work the physicists will have their eyes on goals which are more distant, but no less important.

Future Trends

IT is quite certain that the automotive industry will remain interested in subjects such as those in Tables IV, V, and VI. Considering the great importance of materials to the automotive industry, together with the present concentration by physicists on solid-state problems, it is apparent that these areas will receive much attention. Structural materials such as metals, ceramics, plastics, rubber, and glass offer very interesting and profitable opportunities for research along atomistic lines. The automotive industry is now using increasing numbers of solid-state circuit elements, and is manufacturing transistors. There is a growing interest in advanced vehicle control and communication systems. Thus it is to be expected that the industry will greatly increase research on semiconductors, insulators, new magnetic materials, and other solids associated with advanced electronics.

All forms of energy conversion will be scrutinized including chemical and nuclear reactions, thermionic and thermoelectric generators and fuel cells. Energy storage methods, particularly batteries and new fuels, are an important challenge to the physicist.

The physicists will continue in cooperative efforts, with their colleagues from other disciplines, to attack the long-range problems of the industry involving human engineering, traffic, vehicle control, advanced vehicle planning, and new transportation systems.

Remarks on Training

IAM continually amazed at how much our young college graduates and PhD's know today in comparison with what was expected of us thirty years ago. The universities are to be commended for their success in adapting their curriculums to the changing aspects of science and for somehow crowding more work into the academic year.

There are some qualities, however, which the automotive industry and all other industries consider to be of great value, which are generally not taught in school; for example, breadth-of-interest and creativity. These qualities are perhaps cultivated rather than taught;

nevertheless, university faculties can and do have a great influence on their students in this regard.

In examining the possibilities for the application of physics in the automotive industry one must be impressed with the wide range of science and technology involved and it is apparent that industry needs scientists with great breadth of interest. We grant at once that this is an age of specialization, but we have all known specialists who could contribute ideas to the projects of their colleagues and who, when the circumstances demanded it, could leave their narrow specialties and move successfully into other areas. Today we occasionally find a young PhD who will not consider working on a project unless it is an extension of his PhD research. In fact, it appears that he considers this as a life work rather than as an educational device. Obviously, this is not a good attitude for his own future in the rapidly changing world of physics, and such a man is not very adaptable to the changing requirements of industry. Wide interests and ready adaptability are of tremendous value.

Creativity, ingenuity, or inventiveness, whatever we wish to call it, is also most important in industry. Advanced training by no means guarantees this quality. Many years of educational regimentation take their toll of creativity. Throughout his whole school life the student learns to reproduce the creative thinking of others. Then suddenly, perhaps when he starts his PhD research, we call on him to be creative, to look for new ways of doing things, and to question current dogma. Although this is of vital importance it is usually not easy for him.

These are two great challenges to our universities, to stimulate broad interests in men who must be specialists and to cultivate creativity in men who must accumulate a tremendous store of recorded knowledge.

The automotive industry has great opportunities for the application of physics. Whether physicists will be able to meet the challenge of these opportunities depends in a large part on the breadth of their interests, on their adaptability to new situations, and on their capabilities for independent thought and action.

References

1. E. W. Weller and E. A. Hanzysz, *Iron Age*, **173**, 162 (1954).
2. D. L. Fry, *School Science and Mathematics*, **56**, 341, (May, 1956).
3. A. Somerville, J. P. Danforth, F. L. Green, and D. F. Pierce, *United Nations Peaceful Uses of Atomic Energy*, **1**, 328 (1958). J. P. Danforth. Presented before ASTM, June 22, 1959. (To be published.)
4. S. R. Rouze and W. L. Grube, (Unpublished.)
5. J. V. Laukonis and R. V. Coleman, *J. Appl. Phys.*, **30**, 1364 (1959).
6. J. T. Wentworth and W. A. Daniel, *SAE Trans.*, **63**, 602(1955).
7. W. A. Daniel, *Sixth Symposium (International) on Combustion* (Reinhold Publishing Corp., New York, 1957), p. 886.
8. R. C. Frank, D. E. Swets, and D. L. Fry, *J. Appl. Phys.*, **29**, 892(1958). R. W. Lee, D. E. Swets, R. C. Frank. Presented before Société Française de Metallurgie, Paris, Oct. 19, 1959. (To be published.)
9. R. C. Frank, *Internal Stresses and Fatigue in Metals*, G. M. Rassweiler and W. L. Grube, Editors (Elsevier Press, New York, 1959).
10. F. L. Green and W. D. Cheek, *United Nations Peaceful Uses of Atomic Energy, Proc.*, **19**, 169(1958). F. L. Green and W. D. Cheek. (To be published.)
11. A. A. Vuylsteke and Y. T. Sihvonen, *Phys. Rev.*, **113**, 40(1959).