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ASTROPHYSICS AND INDUSTRY

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It is an oft repeated truism that the problems of astrophysics and physics are essentially alike and fundamentally interrelated; that astrophysics progresses mainly through applications of recent technical discoveries in experimental or theoretical physics; and that, conversely, physics is frequently stimulated by new astronomical observations or theoretical deductions. In such a statement the word "physics" should be taken in its general sense and in particular, should include applied or industrial physics. The similarity between problems or techniques of astronomical and industrial physics is indeed striking, and much may be gained from scientific contacts of astronomers and industrial physicists.

A few examples will illustrate this statement. The photometer is an instrument used by all kinds of physicists, including the illumination engineer, as well as by astronomers. When an astronomer proceeds to color determinations of celestial objects, using an electric receiver and filters, his purpose and technique do not differ from those of a metallurgical physicist determining the accurate color of a solution with his photoelectric colorimeter. Just as the stellar photometrists find it useful to broaden the wavelength range of color determination in order to cover the ultraviolet and the near infrared, so a widening of the range covered in industrial colorimetry is found to be

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fruitful. When astronomers discuss the scattering and absorbing properties of diffuse matter in dark or bright nebulae, in planets, or in comets, they share the interest and kind of work of a chemical physicist engaged in nephelometry (according to Webster: a study of the character of suspensions by means of diffuse transmitted or reflected light). When we try to determine the polarization of the light of the solar corona, the comets, the planets, the zodiacal zone, or interstellar matter, we search for the same information and use essentially the same method as a chemical physicist in determining sugar content with his saccharimeter or as a mechanical engineer engaged in stress analysis with his photoelasticimeter. The interferometric determination of stellar diameters or of double star separations is similar to the delicate interferometric measurements in which many mechanical engineers are engaged. The astrophysicist encounters fluorescence effects over a wide range of temperature, from very low (comets) to very high (nebulae); the chemical physicist also takes advantage of fluorescence effects, at the temperature of liquid air as well as that of the electric furnace. Mass spectrometry which is so fruitful in petroleum and other chemical laboratories is also used for the isotopic analysis of meteorites. The techniques and theories which have led to the tremendous developments of radio, radar, and television find exciting applications in radio- and radar-astronomy. The aerodynamic notions of drag, rocket action, shock waves, etc. which are constantly employed by aeronautical engineers have also gained importance in astronomical investigations of meteors, novae, and solar phenomena. The famous Mach number of which we have read so much in the newspaper articles on supersonic

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speeds is a concept commonly found in certain astronomical papers. Even theoretical and practical considerations of ballistics engineering have gained importance in various chapters of astronomy.

Especially in the fields of optics and spectroscopy the community of interest and methods between astronomical and industrial physicists is apparent. For example: many optical instruments developed for military physics have astronomical possibilities; among them are the sniperscope, the icaroscope, and the lens systems using synthetic crystals of rocksalt, potassium bromide, and the like. The coating of lenses and prisms with fluorides and other compounds has considerably increased the efficiency of the astronomical spectrographs, just as it has improved the contrast and the luminosity in binoculars or tank periscopes. Interference filters possessing fairly narrow transmission regions are as important in industrial photometry as they are for the photography or photometry of celestial objects. Similarly the Schmidt camera, with which astronomers have been familiar for over twenty years, is now finding useful applications in many problems of applied physics in which weak sources of light are handled.

The industrial spectroscopist is closer to the astrophysicist than any other applied physicist. The detection and dosage of metals in a stellar atmosphere is essentially the same problem as the analysis of an alloy. To determine the amount of methane or ammonia in a planet is after all just a spectrochemical analysis of a gas mixture of the kind familiar to physicists in the petroleum or synthetic rubber industries. There is no essential difference in problem or technique between a spectroscopic determination of temperature in a

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sunspot or cold star, and that in an arc used for welding. The theoretical astronomer engaged in the study of the dissociation equilibrium of molecules in a stellar atmosphere has the same theories at his disposal as the chemical physicist investigating the equilibria in furnaces. The industrial spectrosopist would be at a loss without the tables of wave lengths, spectroscopic designations, and intensities prepared by astrophysicists. But then, the investigator of comets finds real help in the work on combustion-, explosion- and flame-spectra carried on by applied physicists. In the astrophysical laboratory in Liège the same spectroscopic installation, including the light source, is used to study peculiar band spectra which are present in comets, and to determine the gaseous contents of steel samples!

In astronomy the investigation of the light of the celestial objects is the only method of approach. The industrial physicist is often in a better position since he has other experimental techniques at his disposal; yet he often gives preference to the spectroscopic method on account of its simplicity, its rapidity, its extreme sensitivity, the small amount of material required, the simultaneous detection of many (often all) compounds, and the fact that a record (photograph or tracing) remains. In many industrial plants spectroscopic analysis has entirely superseded chemical analysis in the control of production as well as in laboratory research.

It is especially in metallurgy (including the automobile, airplane, rocket, telephone, cable, and electrical industries) that applied spectroscopy has revealed its efficiency. However, the literature on the applications of physics in recent years reveals the important part which spectroscopy has also

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played in the other following fields:

- chemical industries (traces of metals in dyestuffs, oil, . . .; studies of dyes, enzymes, . . .) ;
- glass and ceramics industries;
- geology including geochemistry, hydrology, volcanology (study of mineral and lake waters, sands, rocks, ores, . . .) ;
- mineralogy (identification of minerals, jades, . . .) ;
- food and beverage industries (traces of metals) ;
- agriculture and horticulture (study of soils, fertilizers, waters, grasses, . . .; mineral elements in fruits, vegetables, . . .) ;
- medicine (metals in various organs; action of drugs on specific organs; measurement of fast reactions and its application to respiratory enzyme kinetics; . . .) ;
- hygiene (composition of industrial dusts, . . .) ;
- criminology (traces of substances, such as arsenic or alcaloids) ;
- pharmacy (detection of metals in organic compounds; studies of vitamins, hormones, proteins, porphyrins, blood, etc. . . .).

Some astronomers remember the pioneering stages of astrophysics when stellar spectroscopy was only visual. There is still a place, and an important one, in industry for visual spectroscopy. Samples of alloy steel bars, scrap, aluminum, etc. can be classified very rapidly by simple visual examination of their spectra. It has been mentioned that mixed stock is a real problem to manufacturers who make or use steel; visual spectroscopy in this case would be quite appropriate for the rapid detection of fairly low percentages of *Al*, *Ni*, *Cr*, *Mo*, *Mn*, *Ti*, *W*, *Co*, *Cu*, *Sn*, *Cd*; *V*, *Pb*, and *Si*. Visual methods are used in several industrial plants, and it may be possible to extend them to

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the ultraviolet by using fluorescent screens.

Industrial spectroscopists profit by the techniques and theories of the astrophysicists, and vice versa. Until recently, applied physicists did not pay too much attention to the luminosity in their spectrographs, since they had plenty of light at their disposal from arcs, sparks, or flames. Then recently came the possibilities of important industrial applications of methods such as the Raman scattering and the microspark. These are laboratory light sources which are very poor in light. The astronomer has been faced with this problem of weak light sources (that is faint stars, or nebulae, or comets) for a long time and has developed fast spectrographs using optical systems of high luminosity, such as Schmidt cameras. The industrial physicists engaged in Raman- or micro-spectrography have simply to duplicate these astronomical spectrographs.

Certain instruments which the astronomer has been using for years have not yet been applied in industry, but doubtless they will in time be introduced. For example, astronomers have developed the polarizing monochromator which enables them to observe solar phenomena in monochromatic light. It would seem that such an instrument should enable industrial physicists to make rapid routine dosages of various elements in alloys with little effort. One such instrument designed for the aluminum industry (determination of magnesium) will soon be in operation. Indeed an instrument embodying a similar principle may become important in the glass industry, since it would enable the easy examination of the interiors of furnaces at high temperature for a study of the motion of the gases or for an examination of the explosions of bubbles within the molten glass.

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The industrial spectroscopist often needs the results of his analysis in a short time, since a whole metallurgical or chemical operation may depend on such a quick analysis. Hence, he has been compelled to develop methods of direct electronic recording, instead of employing the usual photographic plate. The astronomical application of similar methods will eventually bring important results.

The usual spectral range covered by the astronomers extends from the near ultraviolet to the red. Occasionally the photographic infrared region has also been covered, always with fruitful results. An extension toward the short wave lengths requires rocket observations above the ozone layer; interesting data on the ultraviolet solar spectrum have thus been obtained. However, it is mostly toward the longer wave lengths that the extension of the astronomical range proves practicable and efficient. The industrial physicists have done a considerable amount of work in the infrared region, which is of tremendous importance for the detection and dosage of many organic substances, such as those of interest in the petroleum and synthetic rubber industries. New thermopiles and bolometers have been developed which are now available to astronomers. The most sensitive receiver in the region from one to three microns is the lead sulphide cell which was developed for problems of applied physics. With proper electronic amplifiers (developed by specialists in electronics) it has recently led to most interesting astronomical results. Further laboratory developments of infrared techniques, including those based on cumulative effects, are awaited by astronomers with keen interest.

During the world wars many astronomers de-

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voted their efforts to technical problems of military importance. Most of them found that their astronomical training helped them greatly. Astronomers are also able to help industry in peacetime, whenever circumstances require such help. This was fully realized in Western Europe around 1945 when the whole industrial organization, partly wrecked by the war and partly outdated, had to be reconstructed on an up-to-date basis. Whenever astronomers were called for help or advice, their cooperation with metallurgical and chemical plants or with glass factories was appreciated, especially in the field of optics. Obviously the benefit works both ways!

Most important observatories have on their staff a civil engineer or a physicist whose training and experience are considered, and rightly so, of extreme help in the construction and maintenance of the numerous mechanical and electrical instruments as well as of the telescopes. Nowadays a person with good training in electronics is just as essential. But this is not sufficient. Astronomers must keep themselves informed to some general extent on the main developments resulting from the work of the industrial physicists. It is in this way that they will be sure to take the fullest advantage of the admirable laboratories provided for them by the celestial objects. Similarly the industrial physicists would do well to visit astrophysical observatories from time to time.

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