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FLUORESCENCE IN ASTRONOMY

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Cunningham's Comet, photographed on January 2, 1941, by van Biesbroeck at the Yerkes Observatory. The light of this comet is almost entirely the result of fluorescence.

When invisible ultraviolet light shines on certain substances, such as the tungsten ore scheelite, they give off visible light. This phenomenon is called fluorescence. Prospectors for tungsten sometimes carry an ultraviolet lamp, the rays from which are made to fall on specimens of rock which may contain scheelite. The ultraviolet rays are practically invisible so that the rocks can not be seen by reflected light, but if scheelite is present it glows with a whitish light making it easily visible.

Some of the atoms or molecules of the scheelite are brought into an "activated" state when they absorb the ultraviolet light, but they cannot remain long in that state. Hence the energy of activation is released in the form of a whitish glow for a very short interval of time after the excitation. The wave lengths of the fluorescent emissions, which are characteristic of the substance, are usually longer than the exciting radiations. If, as is generally true, the average lifetime of the activated molecules is extremely short, say of the order of a ten millionth of a second, the phenomenon is called fluorescence; then the induced emission ceases almost as soon as the exciting light is switched off. Some substances retain their activated state for a long time (sometimes as long as several hours) and do not stop glowing when the activating light ceases. Such prolonged emission is called phosphorescence.

Fluorescence has received many technical applications in recent years. The most remarkable is the fluorescent lamp, the most economical source of light yet developed for factories, offices, and schools. We have heard recently of fluorescent powders or solutions being used in a wide variety of problems relating to the Armed Forces. Hundreds of applications are found in industrial chemistry, the biological and mineral sciences, criminology, and toxicology. The oils and synthetic rubbers, certain vitamins and hormones, and many other organic chemicals of importance to the biologist have specific fluorescences which may help in recognizing them. In criminology fluorescence helps to detect falsifications of documents by finding traces of invisible ink and it is also used in locating morphine and other similar drugs. The principle is always the same: invisible ultraviolet light is transformed into visible fluorescence, which being characteristic of the activated substance, serves to identify it. Fluorescence is now also beginning to find an increasingly important place in astrophysics.

In the fluorescent lamp the primary light is that of an electric discharge in mercury vapor. This primary light contains much invisible ultraviolet radiation which is of no practical use for illumination. Substances which will absorb this invisible ultraviolet radiation and convert it by fluorescence into visible light are placed in the mercury discharge tube in such a way that they receive as much ultraviolet emission as possible from the mercury arc. The color and intensity of the fluorescent light may even be combined with that of the primary source so that the total emission has a desired color, for example that of sunlight. In this way fairly good "daylight" lamps have been made, but further improvements are still desirable.

The fluorescent substance may be a solid, a liquid, or a gas. In most solids, liquids or dense gases an activated atom or molecule may be influenced by its neighbors, even if they are not of the same chemical nature. The corresponding perturbing effect on the fluorescent radiation will depend on many complex factors. Happily in all astronomical problems in which fluorescence plays a role—and phosphorescence is not to be considered yet—we have to deal with gases at densities so low that the fluorescence is not appreciably affected by collisions or by perturbations due to neighboring atoms.

In what celestial sources should we probably expect to find fluorescence of importance? All celestial bodies should be considered in whose spectra emission lines or bands are observed, if we can find a possible source of exciting radiation. For example, although emission bands occur in the spectrum of the night sky, they cannot be attributed to fluorescence because no source of exciting radiation is available, the sun having already set. In fact fluorescence should be considered even where bright lines are not observed because it may also affect the profiles of absorption lines and cause anomalous intensities in them.

In the solar system fluorescence is certainly the primary factor in the emission from comets and probably is also important in the light emitted from the twilight sky, the solar chromosphere, and certain disturbed regions on the sun. It is also an important factor in the radiation from most gaseous shells, such as those around novae, Wolf-Rayet stars, and the hot stars of classes B and A which have emission lines. The bright line emission in the cool dwarf M stars, the peculiar variable emission lines of the long-period red variables, the hydrogen emission in interstellar space, and the emission of some lines in nebulae are probably influenced by fluorescence.

Fluorescence is not responsible for all emission lines; other methods of excitation are sometimes much more important, especially electron collisions and the recombinations of ions and electrons. But these two mechanisms are not sufficient alone, as has been generally assumed, and it is only by including the phenomena of fluorescence that a satisfactory agreement can be reached between observation and theory.

The situation in celestial bodies is quite analogous to that in terrestrial light sources. In mercury, neon or argon tubes the emitted light is mainly due to electron collisions and the recombinations of ions and electrons; fluorescence plays only a minor role if any, unless some substance which will fluoresce is present at the proper place in the discharge tube. Similarly in celestial bodies fluorescence is important only if atoms or molecules able to absorb the primary exciting radiation are present at the proper place and in the proper physical condition. One of the essential conditions required to obtain unperturbed fluorescence in gases is low density. Since this condition is amply fulfilled in practically all astronomical sources very pure and efficient fluorescence effects should result.

Fluorescence has recently been investigated with success in the emission bands in the spectra of comets. The relative intensities of the lines in these bands differ completely from anything observed in laboratory sources, and no satisfactory explanation had been found until fluorescence was considered. If a particular cometary line can be excited only by specific wave lengths which are identical with those of strong absorption lines in the solar spectrum, very little solar energy will be available to excite the cometary line because most of it has already been absorbed in the solar atmosphere. Accordingly that cometary line will be weak or absent. Considering the great complexity of the absorption spectrum of the sun, and the strict spectral selectivity of the absorption by the molecules of cometary gases, one may understand that, if the fluorescent process is the essential mechanism of emission, the distribution of intensity among the cometary lines should indeed be very peculiar. The fact that all the details of the intensity distribution in comets can be explained in this way is the first definite observational evidence that light from celestial objects may be excited purely by fluorescence.

Evidently the radiation which affects cometary molecules is the solar radiation just as it is received by the comet, that is, shifted in wave length slightly toward the blue or the red by the relative radial velocity of the sun and the comet. The radial velocity of the sun relative to the comet shifts the solar spectrum toward the red or the violet so that wave lengths which are normally in clear parts of the solar spectrum may fall on an absorption line, or vice versa. Thus the intensity of the solar radiation available to excite a particular cometary line may be critically affected by the relative velocity of the comet and the sun. By taking into account the distance of the comet from the sun and the changes in their relative velocity the variable intensities of the cometary line have been explained by the assumption that the lines are produced by fluorescence.

All other astronomical effects of fluorescence are similar in principle to those in comets: the phenomenon is always very selective, and the primary exciting radiation has almost always absorption or emission characteristics which affect in some way the pattern of the resultant fluorescence. It often happens that fluorescence is excited by radiation of the unobservable far ultraviolet and it seems logical to expect that important data will be obtained concerning the far ultraviolet spectrum of the exciting radiation by a study of its fluorescent effects.

Fluorescence in celestial bodies of low density can be excited only by radiation of sharply defined wave lengths, whereas light produced by other effects, such as ionization or dissociation, may be excited by wide continuous spectral regions. Hence there is good reason to believe that a number of fluorescence phenomena due to far ultraviolet light will be found, which by their unambiguous interpretation will clarify our knowledge of the distribution of energy in inaccessible spectral regions.

The application of the fluorescence phenomena to astronomy is indeed still in its very beginning, but there is no reason why fluorescence should not become as fruitful in astrophysics as it is in other natural or technical sciences.

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