ON FLUORESCENCE RADIATION OF NITROGEN

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In Wood's resonance spectra of iodine vapor, Lenz[1] succeeded in measuring some fundamental constants of the iodine molecule. In an attempt to apply the same methods to other gases, especially hydrogen and nitrogen, some observations have been made upon the fluorescence radiation of the nitrogen ion. These are reported in the present paper.

The main difficulty in exciting fluorescence in hydrogen and nitrogen is that these gases absorb only wave-lengths of the extreme ultra-violet. We cannot, therefore, put a window of any material in the path of the exciting light. Instead, the light source, e.g., a condensed spark, must be put into the same bulb with the gas. Further, the pressure of the gas must be as low as a few tenths of a millimeter, in order to prevent the extinction or change of the fluorescence because of the collisions of the excited molecules.

In the present experiments disturbing electric currents (glow discharges) were prevented by three different means: (1) by enclosing the condensed spark in a glass tube containing one small lateral opening out of which the light could come, (2) by means of a Faraday cage with a small opening into which the light could shine and there excite the fluorescence, (3) by a strong magnetic field parallel to the spark discharge.

In this arrangement a ray coming from the spark excites a faint light in the nitrogen all along its path. This ray is no ordinary electric discharge, nor is it either a cathode ray or a canal ray, as is shown by the fact that it is not at all deflected nor extinguished by a strong magnetic field (7500 gauss) perpendicular to its direction. That it is not a canal ray is further proved by the fact that it keeps well defined rectilinear limits under relatively high pressure (1 mm. of Hg). The exciting ray must then be some sort of light. But, again, the phenomenon cannot be simple scattering of light coming from the spark by the nitrogen molecules, for the spark has an entirely different spectrum from that of the observed light. Besides the latter is extinguished by putting a quartz window in the path of the exciting light. Therefore, it must be assumed that the observed light is the fluorescence radiation of nitrogen, excited by short light waves coming from the spark. The experiment is somewhat similar to Wood's[2] fluorescence excited by "Ultra-Schumann Rays" at atmospheric pressure. The main difference, however, and the one which causes the experimental difficulties, is the application of low pressure in order to produce the simplest type of fluorescence without the disturbances which would be introduced by collisions.

The fluorescence spectrum was first photographed with the aid of a glass spectrograph of strong light power, f/2.7. But even with this sensitivity the fluorescence is so faint that it required an exposure of about eighteen hours to obtain a good plate. This plate revealed a pure band spectrum without any line whatever—a spectrum similar to that obtained from the positive column of a partially exhausted tube. The following bands were observed: 3755, 3805, 3894, 3914, 3943, 3998, 4059, 4142, 4201, 4239, 4281, 4344, 4416, 4489, 4574, 4653, 4709. The bands seem to be complete, and in this respect are unlike Wood's resonance spectra, but on account of the small resolving power of the spectrograph the resolution of the individual bands was not possible.

A striking feature of this spectrum is that it reveals the bands due to the fluorescing ion, as well as the fluorescing neutral molecule. We can distinguish between these two through the work of Wien.[3] He sent a canal ray through the highest vacuum in a direction perpendicular to an electric field. In this way he was able to separate the spectrum of the *undeflected* neutral molecules from the spectrum of the *deflected* ionized molecules. The bands 4709, 4281, 4239, 3914, and probably some others, are thus known to have their origins in the ionized nitrogen molecule. *All of these appear with relatively high intensity in the present fluorescence spectrum.*

It is interesting to inquire by what elementary process we can explain the foregoing excitation of ionized nitrogen molecules. The simplest explanation would involve two steps: first, the ionization of the nitrogen molecule by a sufficiently short wave-length, and, second, the subsequent excitation of this ion. This explanation, however, is not likely the correct one, since it requires a partial pressure of ions comparable to that of neutral molecules.

A second hypothesis seems to be more probable. The nitrogen molecule is similar to the atoms of the alkaline earths in that the spectrum of the ion is excited very easily. For instance, under suitable pressure the spectrum of the nitrogen ion appears quite strong in the positive column of a partially exhausted tube, even at small current densities. The corresponding behavior in the case of the alkaline earths, has been found to be connected with the simultaneous jumping of two electrons within the neutral atom, a phenomenon with which we have become acquainted through the work of Wentzel, Russell and Saunders, and Bowen and Millikan, on the so-called pp' groups.[4] This characteristic of the alkaline earths as distinguished from the alkalis is due to the fact that the former have two electrons in the outer shell. If we assume two-electron jumps within the nitrogen molecule, then by the same process described by Bowen and Millikan the absorption of a wave-length beyond the limit of a series would ionize the atom and, in the same act, excite the ion; just the kind of excitation we need in order to explain the observed radiation of ions in the fluorescence spectrum. This elementary process is by no means proved by the observed facts. It is suggested as a possible explanation only.

There is a third process that might conceivably take place, namely this. Through X-ray absorption one of the inner electrons of the molecule may be removed. The empty place would then be occupied by one of the next outer electrons, and so forth. The last step in this reorganization of the remaining ion, that is, the jump of an outer electron of the ion, may be connected with the visible radiation we observe. In the field of X-rays even *every* secondary radiation is the radiation of an ion, for, by the preceding absorption process, an electron is not only excited but *removed* from the atom.

On the other hand, in the optical region the fluorescence radiation of an ion has not been previously observed. That in ordinary *optical* fluorescence experiments, such as producing iodine fluorescence, no excitation of an ion takes place, is evidently due to the fact that a glass wall or quartz wall prevents the action of the short waves.

That we do not assume two consecutive absorption processes, ionization and in the next step excitation of the ion, is consistent with some observations made by Fulcher[5] twelve years ago. He found that the bands, which according to our present knowledge are due to the nitrogen ion, are strongly excited by high energy electrons (53–60 volts); but these bands disappear entirely as soon as the energy of the electrons drops down below a value between 42 and 35 volts, although this amount of energy would presumably be quite sufficient for excitation in two consecutive steps. So we may assume that the ionization and excitation of the ion are produced with high probability by one single electron impact. This is certainly the case with the helium atom in Rau's[6] experiments and with the magnesium atom in recent experiments of Ruark.[7] Further details will be published later on in connection with other experiments.

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[1] W. Lenz, *Physik. Zs.*, **21**, 692 (1920).

[2] R. W. Wood, *Phil. Mag.*, **30**, 449 (1915).

[3] W. Wien, *Ann. Physik*, **69**, 331 (1923).

[4] Wentzel, *Physik. Zs.*, **24**, 104 (1923), and **25**, 182 (1924); Saunders and Russell, *Physik. Rev.*, **22**, 201 (1923); Bowen and Millikan, *Ibid.*, **26**, 150 (1925).

[5] Fulcher, *Astroph. J.*, **37**, 60 (1913).

[6] Cf. Sommerfeld, *Atombau und Spektrallinien*, 4, Aufl., p. 520.

[7] A. E. Ruark, *J. Opt. Soc. Amer.*, **11**, 199 (1925).