Excitation of Light by Alkali Ions*

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Light emission produced by slow alkali ions in the rare gases was observed for ion accelerating potentials below those necessary to produce ionization. It was found that light could be observed in helium, neon and argon at the lowest ion accelerating potential for the particular alkali ion that lay closest to the gas in the periodic table. A sodium ion beam in neon produced light at lower accelerating potentials than those reported for neon ions in neon.

INTRODUCTION

IN most experiments on the ionization of gases by positive ion impact, the metal parts of the apparatus are exposed to any radiation which may be produced in the ion beam. It is, therefore, of some interest to know at what velocity appreciable amounts of radiation are produced in a beam of ions passing through a gas at low pressure. Since the most complete work on the ionization of gases by slow positive ions has been done on the inert gases and alkali ions, this group of ions and gases were chosen for the present experiment.

APPARATUS

The experimental tube shown in Fig. 1 consists of an ion source, F, two collimating slits, S_1 and S_2, an observation space and a collector, C. The source was a platinum filament coated with natural ores of the alkali silicates by essentially the same process described by Bainbridge.[1] Li^+ ions were obtained from spodumene, Na^+ from jadeite, K^+ from leucite, and Cs^+ from pollucite. These sources tested in a mass-spectrograph were found to emit very small percentages of impurities, in all cases less than 4 percent. The filament was placed 3 mm from the first collimating slit. Each slit was 5 mm in diameter and the slit separation 1 cm. The observation space beyond the slits was 1.5 cm long and the collector at the end of the tube was 5 cm deep. The internal diameter of the tube, and the diameter of the collector were each 3 cm.

The metal parts of the tube were covered with a carbon deposit to cut down scattered light. Since the source gave copious emission of ions when heated to dull red, the scattered light was negligible except at the limit of visibility of the beam.

The gases used were He, Ne, and A, 98 percent pure as they were taken from their containers. They were further purified by the evaporation of K and Ca in the tube at low pressures. In the case of He and Ne a charcoal trap immersed in liquid air was kept on the tube throughout the experiment. The gas pressures were measured by a McLeod gauge connected directly to the tube.

The accelerating potential for the ions applied between the filament and first slit could be varied between 50 and 600 volts. In every case an ion beam of good intensity was obtained for accelerating potentials between 200 and 300 volts with a gas pressure as high as 2×10^{-2} mm. The current which reached the collector, of the order of 10^{-7} ampere, was measured by a galvanometer.

MEASUREMENTS

In the first case[2] tried, Li^+ in Ne, the beam was accelerated into the field free observation space with a flat plate at the mouth of the collector. A clearly visible and fairly well-defined beam extended to the plate. As a retarding field for the ions was applied in the observation space the beam fell short of the plate. Figs. 2 and 3 show two diagrams sketched from photographs of the beam made with a 4.5 lens and Ilford panchromatic plates. The exposure time was two hours.

The method was not satisfactory for determining the velocity of the ions at which excitation was first observed since it was difficult to

* Experiment done during tenure of National Research Fellowship.

[1] K. T. Bainbridge, J. Frank. Inst. **212**, 333 (1931).

[2] A. J. Dempster and R. E. Holzer, Phys. Rev. **43**, 365 (1933).

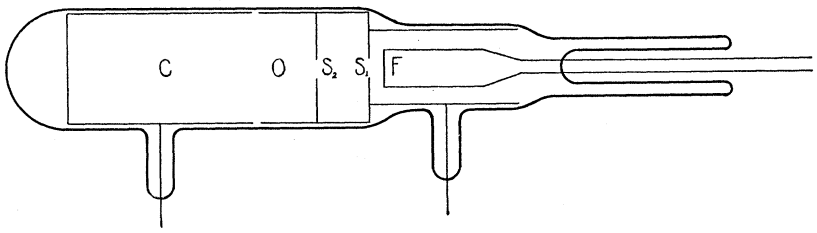


FIG. 1. Experimental tube.

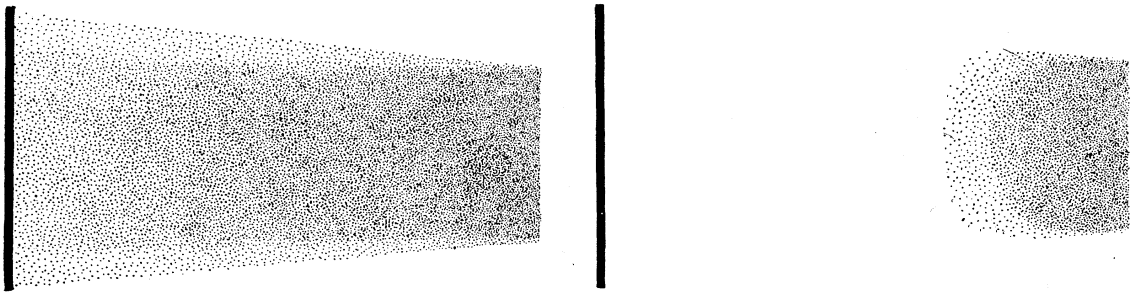
observe the exact limit of the beam and since the camera was not as sensitive as the eye. It was, therefore, abandoned in favor of a direct photometric measurement of the intensity of the beam for Li^+ in Ne and all other ion and gas combinations.

The comparison source consisted of a 25 watt tungsten filament lamp in a shielded box with two apertures approximately the width of the beam at the point measured. The apertures were screened for color matching and intensity reduction. The comparison source was then calibrated against an arbitrary standard.

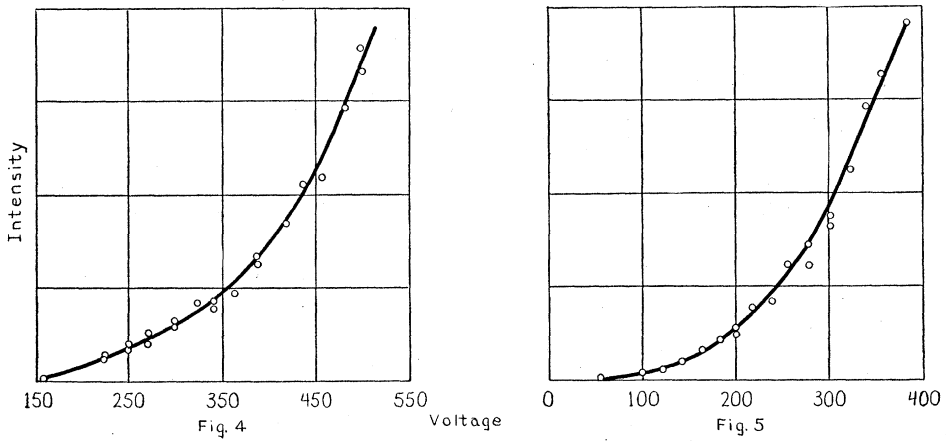
In making photometric measurements the observer remained in a dark room for a period of 20 minutes to sensitize his eyes to faint light. A second observer always regulated the voltages, and read the meters so that the first observer did not have to expose his eyes to light intensity stronger than that from the beam at any time. In taking the readings, one observer always watched the beam and made the photometric settings, the second recorded the accelerating potential, the current to the collector and current in the photometric lamp. Below a certain minimum of light intensity it was impossible to make a satisfactory photometric setting. To determine the least accelerating potential at which light from the beam could be detected the accelerating potential was lowered and the beam flashed off and on. The process was then repeated with increasing accelerating potential.

The curves shown in Figs. 4 and 5 give light intensity in arbitrary units as a function of the accelerating potential of the positive ions. Zero on the scale represents the least observable light intensity. Corrections were made for the decreased current at low voltage.

Several points arise in the interpretation of the results which must be checked experimentally. In the first place, it is possible that gaseous ions were produced in the accelerating field by electrons liberated from the negative plate. These gaseous ions would then be accelerated into the observation space together with the alkali ions from the filament. To determine whether gaseous ions were present in the beam in observable numbers, a bare platinum filament of the same dimensions as the coated filament was substituted for it. The dummy filament was heated to the same temperature and the gas pressure was reduced until no beam of gaseous ions was produced. The pressures used in the experiment were kept well below the point at which a beam of gaseous ions were produced in the accelerating field.



FIGS. 2 AND 3. Sketches of light beam produced by Li^+ ions in Ne. Accelerating potential 600 volts in both cases. Retarding potential zero for Fig. 2, 600 volts for Fig. 3.



FIGS. 4 AND 5. The intensity of the light beam in arbitrary units shown as a function of the ion accelerating potential in volts. Fig. 4 for the case of Li^+ in Ne, Fig. 5 for K^+ in A.

The possibility that a part of the excitation was due to secondary electrons liberated by ion impact at the edges of the slit was also considered. The fact that the beam was deflected only slightly by a magnetic field and in the direction of a positive current indicated that the light was due to the positive ion beam. When the collector was placed in a magnetic field the current was not measurably altered indicating that few secondary electrons liberated from the walls of the collector were escaping the collector and that the current measured was essentially the ion current.

It is also possible that a certain part of the light emitted from the beam is due to excitation of the ions instead of the gas atoms. A spectroscopic examination of the light from the beam was found impractical with the particular experimental arrangement since it was calculated that the minimum exposure for satisfactory plates was some 200 hours. However, the fact that in every case the color of the beam was characteristic of the gas rather than the ion suggests that the major part of the light was due to excitation of the gas atoms rather than the ions. The color of the beam for all ions was red in neon, blue in argon and yellowish green in helium.

The current to the collector was approximately a correct measure of the number of ions in the beam. Using the available data[3, 4, 5, 6] on free paths of alkali ions in gases, it was found that for the particular pressure and lowest ion velocities used in the present experiment, 60 percent of the ions that pass S_1 should enter the collector for the case of Cs^+ in A, while 95 percent of the ions should reach the collector for Li^+ in He. The free path data used in these calculations were all obtained with collectors of small aperture. Since the angle subtended by the collector at S_1 was 110° and since for large aperture collectors the apparent free path is larger than for small aperture collectors,[6] the percentage of the ions reaching the collector is actually much higher than calculated above. The error introduced by neglecting free path calculations is no larger than that in estimating the light intensity of weak beams.

Measurements were made on the minimum accelerating potential in volts at which light from a beam of ions of 10^{-7} amperes would produce an observable amount of light at a gas pressure of 10^{-2} mm of mercury. Li^+, Na^+, K^+ and Cs^+ ions were used in each of the three gases, He, Ne and A. The results are given in Table I.

TABLE I. *Minimum potential for the excitation of light by positive ion impact.*

	Li^+	Na^+	K^+	Cs^+
He	140	152	200	280
Ne	150	128	140	192
A	60	64	60	120

[3] F. M. Durbin, Phys. Rev. **30**, 844 (1927).
[4] C. Ramsauer and O. Beeck, Ann. d. Physik **87**, 1 (1928).
[5] R. Kennard, Phys. Rev. **31**, 423 (1928).
[6] J. S. Thompson, Phys. Rev. **35**, 1196 (1930).

Conclusions

It is interesting to note that light excitation was observed in every case well below the ionization potentials reported by Beeck and Mouzon[7, 8] for the corresponding cases.

It is also interesting to note that the light beam was observed at the lowest accelerating potentials for those cases in which Beeck and Mouzon observed lowest ionization potentials. That is, for any gas the light beam was observed at the lowest ion accelerating potential for that ion which is closest to the gas in the periodic table.

The minimum accelerating potential at which Na^+ ions were able to produce a visible light beam in Ne was approximately 130 volts while Güntherschulze and Keller[9] have found that Ne atoms do not produce excitation in Ne below 300 volts. This agrees with the prediction of Weizel[10] based on the theory of ionization by impact developed by Weizel and Beeck. He states that ionization and excitation of light in the inert gases may be produced at lower energies by alkali ions than ions of the inert gases; applied to this specific case, ionization and excitation may be produced in Ne at lower energies if Na^+ is the moving particle rather than Ne^+.

In conclusion, the writer wishes to express his appreciation to Professor A. J. Dempster for his valuable criticisms of this work.

[7] O. Beeck and J. C. Mouzon, Ann. d. Physik **11**, 737 (1931).
[8] O. Beeck and J. C. Mouzon, Ann. d. Physik **11**, 858 (1931).
[9] A. Güntherschulze and F. Keller, Zeits. f. Physik **72**, 143 (1931).
[10] W. Weizel, Zeits. f. Physik **76**, 259 (1932).

Relative Multiplet Transition Probabilities from Spectroscopic Stability*

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With the method based on the principle of spectroscopic stability, the relative transition probabilities of different multiplets in Russell-Saunders coupling have been calculated for the transitions d^3p-d^4, dp^2-pd^2, and $d^2p^2-d^3p$. A formula is given for getting the transition probabilities, in terms of the core transition probabilities, for the pair of electron configurations which are obtained by adding the same non-equivalent s electron to each core configuration.

Theory

THE method, based on the principle of spectroscopic stability, of calculating the relative transition probabilities of different multiplets in Russell-Saunders coupling has been given by Condon and one of us.[1] This method is used here to calculate the transition probabilities for the transitions d^3p-d^4, dp^2-pd^2, and $d^2p^2-d^3p$. The results of these calculations are given for d^3p-d^4 in Table I, dp^2-pd^2 in Table II, and $d^2p^2-d^3p$ in Table III, where the notation is the same as that used in the previous paper.[1]

We have also found a simple formula for getting the transition probabilities which arise when a non-equivalent s electron is added to a pair of core configurations. These transition probabilities are given in terms of those between the two core configurations. The added s electron must not be equivalent to any core electrons either in the initial or the final state. The relative transition probability in Russell-Saunders coupling is given by

$$(asN\,^{2S+1}L,\ a'sN'\,^{2S+1}L')$$
$$=(2S+1)[1/(2S+2)(aN\,^{2S+2}L,\ a'N'\,^{2S+2}L')$$
$$+(1/2S)(aN\,^{2S}L,\ a'N'\,^{2S}L')], \quad (1)$$

where S is the total spin angular momentum, L

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[1] E. U. Condon and C. W. Ufford, Phys. Rev. **44**, 740 (1933).