TABLE I. Isotopic composition of xenon and krypton before and after irradiation.

| Mass | Normal krypton: Percent unirradiated | Normal krypton: Abundance irradiated | Normal krypton: Percent change | Fission product krypton: Percent unirradiated | Fission product krypton: Abundance irradiated | Fission product krypton: Percent change |
|---|---|---|---|---|---|---|
| 80 | 2.27 | 2.24 | −1.3 ±0.2 | | | |
| 82 | 11.52 | 11.45 | −0.6 ±0.2 | | | |
| 83 | 11.48 | 11.12 | −3.2 ±0.1 | 14.45 | 14.13 | −2.3 ±0.1 |
| 84 | 57.29 | 57.67 | +0.7 ±0.2 | 27.75 | 28.21 | +1.7 ±0.2 |
| 85 | | | | 5.85 | 5.83 | −0.3 ±0.2 |
| 86 | 17.44 | 17.52 | +0.5 ±0.2 | 51.96 | 51.85 | −0.2 ±0.2 |
| | Normal xenon | | | Fission product xenon | | |
| 128 | 1.89 | 1.90 | +0.5 ±0.5 | | | |
| 129 | 26.41 | 26.24 | −0.6 ±0.2 | | | |
| 130 | 4.03 | 4.17 | +3.4 ±1.5 | | | |
| 131 | 21.24 | 20.85 | −1.9 ±0.2 | 13.17 | 13.01 | −1.2 ±0.1 |
| 132 | 27.00 | 27.34 | +1.3 ±0.2 | 19.83 | 20.13 | +1.5 ±0.2 |
| 134 | 10.49 | 10.52 | +0.3 ±0.2 | 36.15 | 36.16 | +0.1 ±0.1 |
| 136 | 8.93 | 8.97 | +0.4 ±0.3 | 30.87 | 30.71 | −0.5 ±0.3 |

and unirradiated samples were measured with a 180-degree direction focusing mass spectrometer. The results are given in Table I.

Assuming that only $(n,\gamma)$ reactions are taking place and that we are concerned only with stable isotopes and $Kr^{85}$ (9.4 yr.) the equation $n=n_0e^{-\sigma FT}$ can be used to calculate the isotopic absorption cross sections. $F$ is the neutron flux, $T$ is the time of irradiation, $\sigma$ is the absorption cross section of the isotope, $n_0$ and $n$ are the abundances of a given isotope before and after irradiation respectively. The data for both normal and fission product samples were used to calculate the neutron capture cross sections. The results are given in Table II. The relative cross-section values are more reliable than are the absolute values. This is due to the fact that the absolute values depend on the neutron flux and the time of irradiation, which are not accurately known, whereas the relative values depend only on the mass spectrometer measurements which are good to 0.5 percent or better.

The mass spectrometer analysis showed that less than 1:15,000 of $Kr^{85}$ (9.4 yr.) was produced from $Kr^{84}$ by neutron capture. This is further evidence that $Kr^{84}$ has a very low capture cross section. Since 40 percent of the total capture of $Kr^{84}$ produce 9.4-yr. $Kr^{85}$, it is possible to assume that no measurable change in the fission product $Kr^{85}$ is due to a feeding in from $Kr^{84}$.

The results show that $Kr^{80}$, $Kr^{83}$, $Xe^{129}$, and $Xe^{131}$ have relatively high absorption cross sections. It is interesting to note that $Xe^{129}$, $Xe^{131}$, and $Kr^{83}$, which have an odd number of neutrons, have the highest cross sections. Neutron capture cross-section data reported to date seem to indicate that this is a general rule. However, the low value for $Kr^{85}$ is an exception to this rule.

It is apparent from these results that $Kr^{85}$, which has one neutron less than a closed shell, does not have an exceptionally high thermal neutron capture cross section. This, however, does not preclude the possibility of a high resonance cross section at higher neutron energies than are generally obtained in the Chalk River pile. The low cross sections found for $Kr^{84}$, $Kr^{86}$, $Xe^{134}$, and $Xe^{136}$ are not surprising in view of the nuclear structure postulated for these isotopes.

TABLE II. Neutron capture cross sections of xenon and krypton.

| Krypton Mass | Krypton Isotopic cross section in barns | Xenon Mass | Xenon Isotopic cross section in barns |
|---|---|---|---|
| 78 | (0.27)* | 128 | 5 > 0 |
| 80 | 95 ±15 | 129 | 45 ±15 |
| 82 | 45 ±15 | 130 | 5 > 0 |
| 83 | 205 ±10 | 131 | 120 ±15 |
| 84 | 2 > 0.1 (0.156) | 132 | 5 > 0 (0.02) |
| 85 | 15 > 0 | 134 | 5 > 0 (0.02) |
| 86 | 2 > 0 (0.064) | 136 | 5 > 0 (0.15) |
| Total absorption cross section in barns | | | |
| Our results | 30 ±5 | | 37 ±5 |
| Reported (absorption and scattering) | 27 | | 40 |

* The cross sections given in brackets are the known activation cross sections (reference 1).

We wish to thank W. E. Grummitt for his assistance in getting the samples irradiated. We also wish to thank the National Research Council of Canada for financial assistance and to acknowledge the use of the facilities of the Chalk River pile.

[1] W. H. Sullivan, *Trilinear Chart of Nuclear Species* (John Wiley and Sons, Inc., New York, 1949).

## The Mobilities of Molecular and Atomic Rare Gas Ions in the Parent Gases: Helium, Neon, and Argon

JOHN A. HORNBECK
*Bell Telephone Laboratories, Murray Hill, New Jersey*
July 20, 1950

EXPERIMENT and theory disagree on the low field mobility ($\mu_0$) of the ion $He^+$ in helium. Tyndall and Powell[1] obtained[2] $\mu_0=19.9$ cm²/volt-sec. after being dissatisfied with an earlier measurement[3] of 12. Biondi and Brown[4] from diffusion data obtained 12.8. Although classical kinetic theory[5] predicts $\mu_0=19.6$, a careful quantum-mechanical calculation of Massey and Mohr[6] predicts 11.

Meyerott[7] has suggested that these discrepancies are removed if (a) the value $\mu_0=19.9$ of Tyndall and Powell applies to $He_2^+$ rather than $He^+$, and (b) the superiority of the quantum-mechanical computation is recognized. The situation is further complicated, however, by Bates[8] suggestion that, because of ion age, Biondi and Brown also dealt partly with $He_2^+$.

Ion mobility measurements have been made in these Laboratories in the course of experiments on pulsed Townsend discharges. The transient current resulting from the liberation of a very short (0.1-μsec.) pulse of photo-electrons from the cathode of a gas-filled tube agrees well with the theory of Newton.[9] The predicted and observed discontinuity in current, corresponding to one ion transit time across the tube, permits measurement of the ion drift velocity (or mobility) as a function of $E/p_0$. In the gases studied, helium, neon, and argon, one discontinuity is observed over a range of $E/p_0$ from several hundred (units of volts/cm-mm Hg) to about 25. At lower $E/p_0$ two discontinuities have been observed consistently indicating the presence of two species of ions with different mobilities.

The ion appearing only at low $E/p_0$ in each gas has a mobility about twice that of the other ion. In the region where both ions were observed in helium, the age of the slow ion was never more than 30 μsec. and the fast ion never more than 15 μsec. At $E/p_0=10$ in helium the respective mobilities of the fast and slow ions were $\mu_{fast}=18$ and $\mu_{slow}=9.4$, and these values were increasing slowly as $E/p_0$ was decreased. Measurements at lower $E/p_0$ could not be carried out.

In this experiment the sharp time definition of the current discontinuity demands that the ions be formed within one microsecond after the photo-pulse and that the ions not change their identity during the transit across the tube.

The slow ion in each of the rare gases we identify as the atomic ion, $He^+$, $Ne^+$, and $A^+$, primarily on the basis that the slow ion is observed over the entire range of $E/p_0$. This implies, for example, an $He^+$ age of one μsec. at the highest $E/p_0$ obtained.

The identity of the fast ion might be (a) doubly charged atomic ion, (b) impurity ion, (c) molecular ion of the parent gas. Hypothesis (a) is unsatisfactory because the fast ion appears only at low $E/p_0$ and because the voltage applied to the electrodes was in some cases less than the appearance potential of the doubly charged ion. Time considerations suggest that an impurity concentration of the order of one percent or possibly more would be required to make hypothesis (b) reasonable. Mass spectrometer analyses of the gases used indicated no impurity within the limit

of sensitivity of the instrument (0.005 percent). Flashing additional Ba-Mg getters in the experimental tube did not alter the effect. The impurity hypothesis, therefore, appears to be untenable.

Turning to hypothesis (c), the proposed mechanism of formation of the molecular ions[10] (suggested to the author by C. Herring) is that atoms excited by the primary electron pulse to a high state above the metastable level may collide with neutral atoms before they radiate, giving the molecular ion and an electron.[11] The molecular ion hypothesis based on this formation process seems consistent in every respect. First, $He_2^+$, $Ne_2^+$, and $A_2^+$ are known to exist.[12] Second, the other factors that we have to consider, *viz.*, time of formation, energy of formation, pressure variation, and mobility, all agree with other experimental observations and theory to the extent that these are available or known.

The suggestion of Meyerott therefore seems to be well substantiated, namely, that the identity of the ion measured in some experiments has been confused, and that the calculation of Massey and Mohr for helium is essentially correct. From the present measurements of $A_2^+$, $A^+$, and $Ne_2^+$ and $Ne^+$, one concludes that the exchange force reduces the mobility of the atomic ions (making them slower than the molecular ions) by about the same factor that this force reduces the mobility of $He^+$ in helium. The results indicate, further, that the mobility measurements of Munson and Tyndall[13] presented as $A^+$ in argon and $Ne^+$ in neon actually are for $A_2^+$ and $Ne_2^+$.

I am greatly indebted to many of my colleagues, particularly Dr. J. P. Molnar, Dr. G. H. Wannier, and Mr. A. H. White, for their invaluable assistance and advice in the course of this work.

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[5] H. R. Hasse and W. R. Cook, Phil. Mag. **12**, 554 (1931).
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[7] R. Meyerott, Phys. Rev. **66**, 242 (1944); **70**, 671 (1946).
[8] D. R. Bates, Phys. Rev. **77**, 718 (1950).
[9] R. R. Newton, Phys. Rev. **73**, 570 (1948).
[10] F. L. Arnot and M. B. M'Ewen, Proc. Roy. Soc. **A166**, 550 (1938), have suggested the same mechanism as a corollary to a formation process from a metastable atom-neutral atom collision.
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## The Electric Field at a Thermionic Cathode as a Function of Space Current

PAUL L. COPELAND AND DELBERT N. EGGENBERGER
*Illinois Institute of Technology and Armour and Company, Chicago, Illinois*
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THE work of Ivey[1] suggests that the field at the cathode of any diode is a simple function of $i \equiv I/I_s$, where $I$ is the space current and $I_s$ is the space-charge limited current in this diode. For simple symmetries (parallel planes, coaxial cylinders, and concentric spheres) the potential or the potential gradient are most easily expressed in terms of a harmonic coordinate $z$ such that Laplace's equation takes the form $d^2V/dz^2=0$. The relationship between the "gradient" at the cathode in the absence of space charge $(dV/dz)_0$ and the "gradient" at the cathode when current flows $(dV/dz)_c$, we express as a Maclaurin's series in $i$ as follows:

$$(dV/dz)_c=(dV/dz)_0(1-ai-bi^2-ci^3-\cdots). \quad (1)$$

From Eq. (17) of Ivey's paper we obtain $a=0.59259$, $b=0.10974$, and $c=0.052025$. If the conjecture put forward by Ivey is correct, $a$, $b$, and $c$ do not depend on geometry.

We have expanded the potential $V(z)$ as a function of $i$ by means of a Maclaurin's series, and through this series have evaluated the coefficient "$a$" in Eq. (1) for various ratios of the radii in the case of coaxial cylinders. The results of our calculations are summarized in Table I. These results suggest that the function expressing the ratio of the field at the cathode in the absence of current to that in the presence of current is not a universal one as Ivey tentatively suggests, but that the ratio $(dV/dz)_c/(dV/dz)_0$ is a slowly varying function of geometry.

TABLE I. Coefficient $a$ in Eq. (1).

| $r/r_c$ | $a$ |
|---|---|
| 1.1 | 0.5926 |
| 5.0 | 0.5913 |
| 10.0 | 0.5896 |
| 100. | 0.5729 |
| 1000. | 0.5422 |

[1] H. F. Ivey, Phys. Rev. **76**, 554 (1949).

## A Determination of the Speed of Light by the Resonant Cavity Method

KEES BOL
*Department of Physics, Stanford University, Stanford, California*
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FOR the last several years an experiment has been in progress at Stanford University for the measurement of the speed of light, $c$, by the resonant microwave cavity method. The cavity consists of a cylinder 4.5 in. high and 9.8 in. i.d., which rests on one end plate, and three spacer rods inserted in the cylinder walls which support the top end plate. The $TE_{012}$ and $Te_{021}$ modes are both measured and are then used to eliminate the measurement of the absolute diameter. The height is found from the spacer rods, which are measured interferometrically.

The provisional result which has been obtained to date is

$$c=299{,}789.3\pm0.4 \text{ km/sec.}$$

The limits given do not include a possible systematic error due to a slight tarnish of the silver-plated walls of the cavity. On this account the result may be too low by possibly as much as, but probably less than, 0.5 km/sec. The experiment is being repeated at present in order to eliminate this difficulty, as well as some others of lesser importance. A detailed paper will be submitted on the completion of this work.

The experiment was devised by the late Dr. W. W. Hansen and was conducted under his supervision until his death.

## The Structure of Lead Sulfide Films

J. A. JAMES, C. J. MILNER, AND B. N. WATTS
*Research Laboratory, The British Thomson-Houston Company, Ltd., Rugby, England*
August 28, 1950

IN the course of work on the development of lead sulfide photoconductive cells, mainly using the chemical method, we have examined the chemical precipitate by x-ray diffraction. We obtained powder patterns which, as reported by Doughty, Lark-Horovitz, Roth, and Shapiro,[1] showed, mainly, lines due to Pbs, with additional lines. In our case, these were definitely identified as being due partly to PbO, and partly to basic lead carbonate $Pb(OH)_2 \cdot PbCO_3$; and not to $PbO \cdot PbSO_4$ as the above authors consider probable.

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[1] Doughty, Lark-Horovitz, Roth, and Shapiro, Phys. Rev. **79**, 203A (1950).