Die Expansionsgeschwindigkeit V_s muß dabei größer sein als die Schallgeschwindigkeit des Füllgases, um einen Massentransport zu ermöglichen.

In der Zeit τ ist der Vorläufer eine Strecke

$$D = V_V \cdot \tau$$

gelaufen. Damit gilt

$$\frac{\varrho_{0V}}{\varrho_{0H}} \frac{1}{V_V} = \frac{d_0}{D} \frac{1}{V_s} = \frac{V_H^2}{V_V^3}. \qquad (12)$$

Aus Gln. (7) und (8) ergibt sich, daß V_H^2/V_V^3 im untersuchten Druckbereich konstant ist und den Wert 0,35 μsec/cm für Helium bzw. 0,31 μsec/cm für Argon hat. Mit plausiblen Werten für D und V_s ($D = 10$ cm, $V_s \geqq 1000$ m/sec) ergibt sich $d_0 \leqq 0{,}3$ cm, d. h. ein ebenfalls plausibler Wert.

Zuverlässigere Aussagen über die Entstehung des Vorläufers können nur durch Messungen seiner raum-zeitlichen Entwicklung während einer Entladung erhalten werden. Vermutlich besteht zwischen der Ursache der hier beschriebenen Vorläufer und dem von JAHN, JASKOWSKI und OBERTH [13] gefundenen „Anodenfuß" in Argonentladungen gleicher Geometrie ein enger Zusammenhang. Ein direkter Vergleich ist nicht möglich, da ihre Messungen bei niederen Fülldrucken, kleineren Gefäßdurchmessern und kleineren Spannungen erfolgten.

Diese Arbeit entstand im Rahmen des Förderungsvorhabens FG 1003 des Bundesministeriums für wissenschaftliche Forschung. Alle Experimente und ein Teil der Auswertung wurden in Kiel ausgeführt. Wir danken Herrn Prof. W. LOCHTE-HOLTGREVEN für die uns dabei gewährte großzügige Unterstützung. Herrn U. GROTH verdanken wir viele technische Details und Hilfe bei den Experimenten.

[13] R. G. JAHN u. W. v. JASKOWSKI, Guggenheim Aerospace Propulsion Lab. Princeton University Reports 634 k und 634 j zum NASA Grant NSG-306-63.

Optical Excitation Functions of Neon in the Vacuum Ultraviolet

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Optical excitation functions of Ne I, Ne II, and Ne III spectral lines in the wavelength range of 400—800 Å have been measured with electron energies from 0 to 500 eV. The excited ions are formed by electron impact in a single collision process. The $(2p)^4$ 3s levels of Ne II become populated via autoionizing states of the neon atom. The excitation functions of the neon resonance lines at 736 and 744 Å are strongly pressure dependent due to radiation imprisonment.

So far litte is known about the electron impact excitation of the vacuum ultraviolet lines in the rare gases, especially about simultaneous ionization and excitation. General considerations on the measurement of optical excitation functions can be found in the papers [1, 2]. A synopsis of the literature on excitation functions is also given in [1].

In this work the following processes leading to the emission of VUV spectral lines are investigated:

$$\mathrm{Ne} + e^- \rightarrow \mathrm{Ne}^* + e^-,$$
$$\mathrm{Ne} + e^- \rightarrow \mathrm{Ne}^{+\,*} + 2\,e^-,$$
$$\mathrm{Ne} + e^- \rightarrow \mathrm{Ne}^{++\,*} + 3\,e^-.$$

It is remarkable that even the excited doubly ionized neon is formed in a single step collision process, with a cross section of the order of $1 \cdot 10^{-18}\,\mathrm{cm}^2$.

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[1] B. L. MOISEIWITSCH and S. J. SMITH, Rev. Mod. Phys. **40**, 238 [1968].

1. Apparatus and Experimental Procedure

An electron beam (10 – 200 μA) of variable energy (0 – 500 eV) passes through a collision chamber. The beam is confined by a magnetic field (100 – 400 gauss). The electrode system is heated to 250 °C during the operation, in order to reduce surface contaminations. The apparatus has been described in detail by SROKA [3]. The gas pressure ($3 \cdot 10^{-5} - 5 \cdot 10^{-3}$ Torr) within the collision chamber is measured with a capacitance manometer. Therefore the pressure indication is independent of the special gas.

The radiation emitted from the excited gas is observed at right angles to the beam with a vacuum monochromator (50 cm, Seya-Namioka mounting) and a magnetically focussed electron multiplier. An X-Y recorder registers the light intensity in dependence on the electron energy. The smothed traces of these ex-

[2] D. W. O. HEDDLE, Methods of Exp. Phys. **7**, Part A, 43 [1968].

[3] W. SROKA, Z. Naturforsch. **23 a**, 2004 [1968].

citation functions are corrected with respect to fluctuations of the gas pressure and beam current.

The energy scale is calibrated by means of the well-known threshold potentials of the helium and neon resonance lines at 584 Å and 736/744 Å, respectively.

The error of the measured threshold potentials is lower than 0.6 eV.

The absolute excitation cross sections of the helium resonance lines at 584 Å, 537 Å and 522 Å obtained from [4] and [5] are used as in [3] in order to calibrate the intensity scale. (For the calibration at 461 Å see Section 2.1.) For this purpose gas mixtures with helium were used in [3]. Because of the gas independent pressure indication this is no more necessary here. But the absolute cross sections in neon can only be estimated, because the wavelength dependence of the sensitivity of the apparatus is not well known, particularly at wavelengths below 500 Å. Therefore the cross sections for this wavelength region in Table 1 are given in arbitrary units only.

2. Experimental Results and Discussion

Figure 1 shows a neon spectrum excited by electrons with an energy of 150 eV. The resonance series of neon converging to the ionization limits at about 575 Å appear towards longer wavelengths. At about 490 Å there is a multiplet of Ne III, the lines at shorter wavelengths are multiplets of Ne II. The Ne I spectrum is strongly pressure dependent. The spectrum below 500 Å is independent of the pressure up to $1\cdot10^{-2}$ Torr. In Table 1 the upper levels of the transitions [6, 7] are listed in the second column. The lower level is the ground state of the term system in question.

	λ (Å)	upper level configuration	Q_m	E_m (eV)	threshold potential (eV) exp.	threshold potential (eV) calc.
	743.7	$2p^5\,(^2P^o_{3/2})\,3s$	$3\cdot10^{-18}$ cm^2	40	16.9	16.7
	735.9	$2p^5\,(^2P^o_{1/2})\,3s$	$2\cdot10^{-17}$ cm^2	60	17.0	16.9
			arbitrary units			
A	460.7	$2s\,2p^6\,^2S_{1/2}$	10	250	48.6	48.5
	462.4		5			
B	445–448	$2p^4\,(^3P)\,3s\,^2P$	3	170	50.8	49.5
D	406/407	$2p^4\,(^1D)\,3s\,^2D$	—	175	(54)	52.2
C	488–491	$2s\,2p^5\,^3P^o$	1	300	<89	88.0

Table 1. The wavelengths have been taken from [6, 8] configurations from [6, 7]. Q_m is the estimated maximum excitation cross section at the energy E_m. The calculated threshold potential is the sum of $h\nu$ and the ionization energies.

2.1. *Radiation from Singly and Doubly Ionized Neon*

The measured relative excitation functions are shown in Fig. 2. The estimated maximum excitation cross sections are listed in column 3 of Table 1 in arbitrary units. The transitions A, B, D are marked in the simplified energy level diagram of Ne II in Fig. 3.

The upper levels are populated by simultaneous ionization and excitation from the Ne I ground state. Some of the Ne I series which converge to the ionization limits corresponding to the Ne II levels are indicated in Fig. 3.

The excitation function A for the ejection of a 2s electron has a light upward curvature within the first 10 eV above threshold. The doublet $^2S_{1/2} - {}^2P_{3/2,\,1/2}$ at 460.7/462.4 Å has been resolved in the second order spectrum. The measured intensity ratio is 2 : 1 in accordance to the statistical weights of the

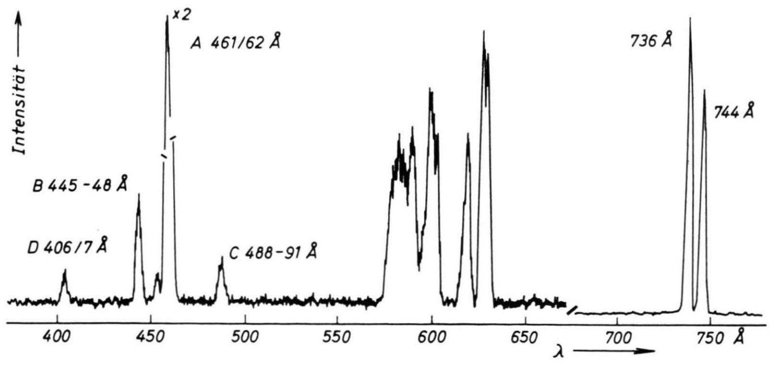

Fig. 1. Neon emission spectrum excited by electrons of $E=150$ eV. $p=1.8\cdot10^{-3}$ Torr. The Ne I-lines have to be corrected with respect to the pressure dependence.

[4] J. D. Jobe and R. M. St. John, Phys. Rev. **164**, 117 [1967].
[5] A. H. Gabriel and D. W. O. Heddle, Proc. Roy. Soc. London A **258**, 124 [1960].
[6] J. C. Boyce, Phys. Rev. **46**, 378 [1934].
[7] Ch. E. Moore, Atomic Energy Levels, Vol. I, Nat. Bur. Stand., Washington 1949.

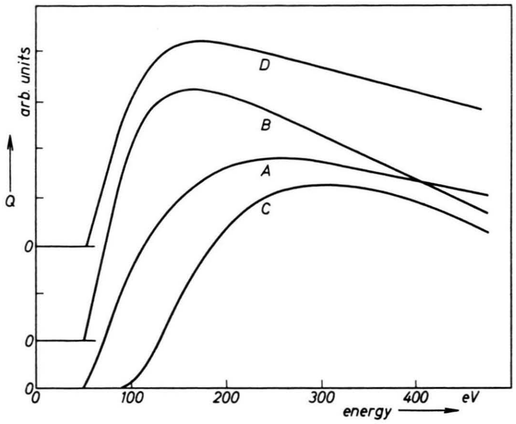

Fig. 2. Relative excitation functions of radiation from the excited ions Ne II and Ne III. The cross sections are listed in Table 1.

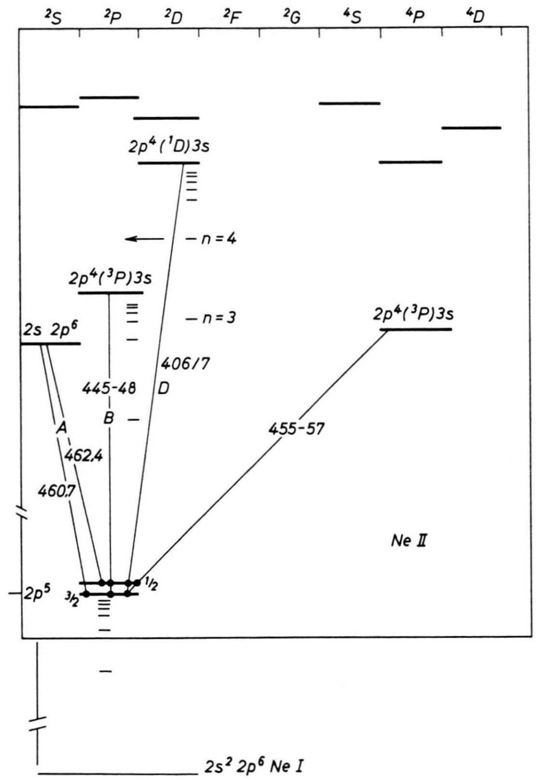

Fig. 3. Simplified energy diagram of Ne II, after [7]. The wavelengths of the transitions are given in Å. Some series of Ne I are indicated in order to ilustrate the text.

lower levels. The relative excitation functions are identical. The absolute excitation cross section of the upper level can be estimated from [9] to be of the order of $1 \cdot 10^{-17}$ cm^2.

The upper levels of the multiplets B and D are populated by the double excitation of two 2p electrons, one of them is ejected and the other one is excited to 3s. The excitation functions appear to rise linearly above threshold. The measured threshold potential of the multiplet B is 1.3 eV greater than the sum of $h\nu$ and the ionization energy.

This fact suggests, that the levels $(2p)^4\,(^3P)\,3s\,^2P$ of Ne II at low energies are populated via the highly excited states $(2p)^4\,(^1D)\,3s\,(^2D)\,n\,p$ of the atom ($n \geqq 4$, see Fig. 3). This excitation is followed by an autoionizing transition into the continuum $(2p)^4\,(^3P)\,3s\,\varepsilon\,p$. The first of these highly excited levels ($n = 4$) is 1.2 eV above the ionization limit $(2p)^4\,(^3P)\,3s\,\varepsilon\,p$ in accordance with the measured threshold potential. The autoionizing states and their interaction with the continuum have been observed in absorption measurements [10]. The measured threshold potential of D is also greater than the calculated one. But this measurement is less accurate because of the low intensity of this multiplet.

The excitation function C for double ionization displays an upward curvature within the first 20 eV above threshold. The upper levels $2s\,(2p)^5$ are excited by the simultaneous ejection of a 2s and a 2p electron. The excitation cross section is smaller by a factor 10 or 20 than that for the ejection of one 2s electron (A).

All these excitation functions depend linearly on the beam current and the gas pressure in the range from $1 \cdot 10^{-4}$ to $6 \cdot 10^{-3}$ Torr. Therefore collision processes other than single step collisions can be excluded. The estimated error of the relative excitation functions is lower than 5%, only in the case of D it is about 10%.

2.2. The 3s Resonance Lines

The intensity of the neon resonance lines is not proportional to the gas pressure. As an example of a typical pressure dependence the apparent excitation cross section (defined as light intensity, divided by the beam current and the gas pressure) of the 736 Å line is plotted against the gas pressure in Fig. 4. The pressure dependence is due to absorption phenomena. The deviation from the exponential

[8] R. L. Kelly, University of California, Lawrence Radiation Laboratory U.C.R.L. 5612.

[9] W. Lotz, Z. Phys. **216**, 241 [1968].

[10] K. Codling, R. P. Madden, and D. L. Ederer, Phys. Rev. **155**, 26 [1967].

law is caused by the change of the line profile of the registered radiation with increasing gas pressure and by the multiple absorption within the collision chamber. The intensity fraction due to cascading from higher levels is also expected to be pressure dependent, because the radiation from these levels is also influenced by resonance radiation imprisonment.

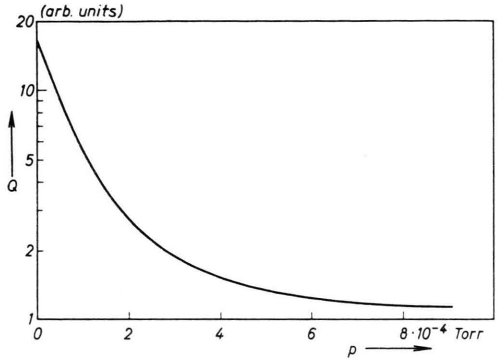

Fig. 4. Apparent excitation cross section Q for the Ne I 736 Å line in arbitrary units versus gas pressure. The Q scale is logarithmic. The electron energy is 64 eV.

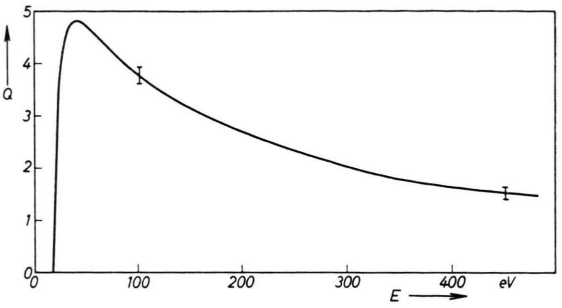

Fig. 6. Relative excitation function of the line 744 Å in the pressure range from $p = 1.1 \cdot 10^{-4}$ to $4 \cdot 10^{-3}$ Torr.

The shape of the excitation function at 744 Å (Fig. 6) is not pressure dependent up to $4 \cdot 10^{-3}$ Torr, although the line is already strongly absorbed at this pressure. Thus it appears to be, at the most, weakly polarized, which can be explained as follows. The excitation cross sections in Table 1 include the population of the resonance levels due to cascading from higher levels. The excitation cross sections for this cascading fraction which can be ob-

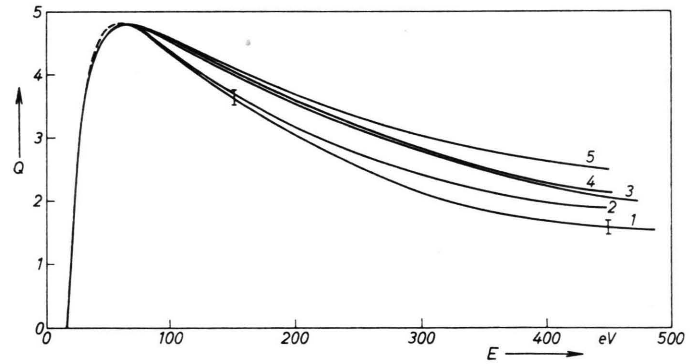

Fig. 5. Relative excitation function at 736 Å at various pressures. For all functions the same arbitrary value of Q_m has been chosen.

no.	1	2	3	4	5
p (10^{-4} Torr)	0.3 – 0.8	3	4.5	19	27

In the case of the 736 Å line the shape of the excitation function is also pressure dependent which is demonstrated in Fig. 5. This dependence is, most probably, due to the fact that the polarization, which depends on the electron energy, is reduced by resonance radiation imprisonment [1, 2]. Therefore the shape becomes more independent of the angle of observation with increasing pressure.

tained from [11] are approximately $6 \cdot 10^{-18}$ cm^2 and $2.5 \cdot 10^{-18}$ cm^2 in the case of the 736 Å and 744 Å lines, respectively. Thus the 744 Å line is mainly excited by cascading and therefore does not show the polarization typical for direct excitation of the upper level.

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[11] P. V. Feltsan, I. P. Zapesochnyi, and M. M. Povch, Ukrain. Fiz. Zh. **11**, 1222 [1966].