Experiments on Resonances in the Elastic Cross Section of Electrons on Rare-Gas Atoms*

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Resonances in the elastic scattering are studied in a scattering experiment at an angle of 72 deg for He and Ne and in a transmission experiment for He, Ne, Kr, and Xe. These resonances result from a compound state of the rare-gas atom and occur about 0.5 eV below the first excited state. The magnitude of the resonances can be enhanced in a transmission experiment when only the unscattered electrons are observed. It is pointed out that the resonance in helium can be used for a determination of the apparent electron energy distribution and as a calibration point on the electron energy scale.

INTRODUCTION

THIS paper discusses experiments on the resonant structure in the elastic cross section using monoenergetic electron-beam techniques. The first experimental evidence that such structure exists was obtained recently by the author in experiments on the scattering of monoenergetic electrons (half-width ~0.060 eV) on helium[1] and neon.[2] This finding had been preceded by theoretical discussions pointing to the possibility that processes of such a nature may exist in the rare gases,[3] and by the finding that vibrational cross sections in N_2 and CO proceed via a compound state of these molecules.[4] These circumstances stimulated the search for resonances in the rare-gas atoms. The existence of the resonance in helium has been now confirmed by several other investigators. Fleming and Higginson[5] have observed the resonance in helium in their modified Maier–Leibnitz-type experiment; at first sight the large resonance observed by these authors with a much broader energy distribution seemed to contradict the results of the author. However, it will be shown in Sec. V that this is not the case and that essential agreement exists. Further, Simpson and Fano,[6] and Simpson and Mielczarek[7] have confirmed the existence of the resonances in a transmission experiment.

Two types of experiments are reported in this paper for a study of the resonances in the elastic scattering. The first type of experiment analyzes electrons scattered at an angle of 72 deg and is discussed in Secs. I and II. The second type, discussed in Secs. III and IV, is a transmission experiment. Both these experiments lead in principle to the same results but each has advantages. The transmission experiment possesses an enhanced sensitivity for the detection of resonances and thus is better suited to those atoms which have a resonance of small magnitude. However, the width of the electron energy distribution obtained in the present transmission experiments is inferior to the width obtained in the scattering experiment by a factor of about 2. However, this is not an inherent limitation of transmission experiments.

I. THE SCATTERING EXPERIMENT

For the original experiment, a double electrostatic analyzer is used which is identical to that used for a study of vibrational excitation[4] of molecules. The first electrostatic analyzer is used for creating a beam of electrons with a half-width about 0.06 eV. The electron beam is accelerated into a collision chamber where it is crossed with an atomic beam. Only those electrons scattered at an angle arbitrarily chosen as 72 deg are accepted by the second electrostatic analyzer. Both electrostatic analyzers pass electrons of about 1.5 eV; the accleration and deceleration of the electrons is achieved near the collision chamber. The potential between the two analyzers is adjusted so that those electrons which have lost no energy (within the resolution of the instrument) are transmitted by the second electrostatic analyzer; thus, the electron current transmitted by the second analyzer is limited to elastically scattered electrons. The electrons are then focused onto the first dynode of an electron multiplier and the output of the electron multiplier is measured on a vibrating-reed electrometer.

The tube is gold-plated to reduce contact potentials and baked at about 400°C. Liquid nitrogen traps are used for trapping the vapor from the 300-liter/sec oil diffusion pumps, even during bakeout of the tube. A background pressure of about 10^{-9} Torr is achieved. Particular attention is paid to the control of the electron energy scale. Especially in the initial experiments on helium it was necessary to establish conclusively that

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[1] G. J. Schulz, Phys. Rev. Letters **10**, 104 (1963).

[2] G. J. Schulz, Third International Conference on the Physics of Electronic and Atomic Collisions, London, July 1963 (unpublished).

[3] E. Baranger and E. Gerjuoy, Phys. Rev. **106**, 1182 (1957); P. G. Burke and H. M. Shey, *ibid.* **126**, 147 (1962).

[4] G. J. Schulz, Phys. Rev. **116**, 1141 (1959).

[5] R. J. Fleming and G. S. Higginson, Proc. Phys. Soc. (London) **81**, 974 (1963).

[6] J. A. Simpson and U. Fano, Phys. Rev. Letters **11**, 158 (1963). See also J. A. Simpson, Third International Conference on the Physics of Electronic and Atomic Collisions, London, 1963 (unpublished).

[7] J. A. Simpson and S. R. Mielczarek, Bull. Am. Phys. Soc. **9**, 89 (1964).

the observed resonance occurs below the onset of the first inelastic process in helium, i.e., the 2^3S state at 19.8 eV. The energy scale is calibrated in three ways: (a) By observing the onset of the ionization process in helium at 24.58 eV. This is accomplished by reversing the polarity on the deflection grids on the second electrostatic analyzer and passing He^+ to the multiplier. (b) By observing the onset of the inelastic process in which electrons have lost 19.8 eV of energy to the excitation of the 2^3S level. To observe this process, a potential of 19.8 eV is applied between the two analyzers, which tunes the system to the inelastically scattered electrons. The accelerating voltage is then varied to obtain the energy dependence of the 2^3S excitation function near its threshold. (c) By calculating the electron energy in the first analyzer from a knowledge of the applied potentials. All three determinations can agree to within 0.05 eV if the tube is in good condition. If the discrepancy is larger than the above value, further baking usually restores the tube, although on occasions it is found that new gold-plating is needed. It is known that large corrections of unknown origin and often attributed to contact potentials may lead to gross uncertainties in the energy scale. The elimination of contact potentials is usually not possible in the presence of reactive gases.

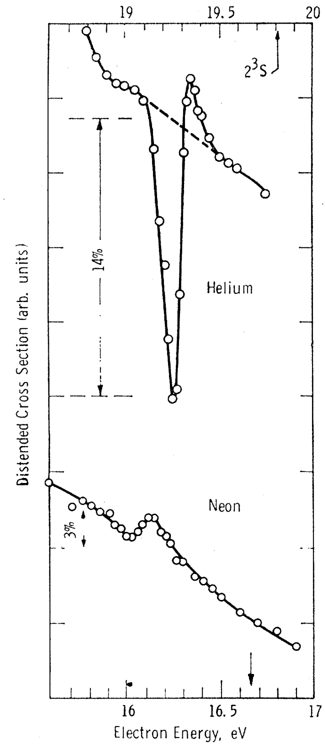

FIG. 1. Energy dependence of the elastic cross section at an angle of 72 deg in helium and neon. The energy scale on top is for the helium curve, on bottom for the neon curve. The dip in helium occurs at 19.30±0.05 eV.

II. RESULTS OF SCATTERING EXPERIMENT

Figure 1 shows the energy dependence of the cross section in helium and neon near their resonances. The zero has been suppressed on the ordinate to show the energy dependence in more detail. In helium, the dip occurs at 19.3±0.05 eV and the half-width is 0.06 eV; i.e., the shape of the resonance is probably broadened by the resolution of the instrument and by the thermal spread of the velocities of the atoms.[6] The curve, which first dips and subsequently rises, is suggestive of the "dispersion" shape found in nuclear reactions.[8] With this half-width, the dip represents 14% of the elastic cross section. The structure is less pronounced in neon; the first dip occurs at 16.0 eV and represents a decrease of only 3% of the elastic cross section. Attempts to find resonances in the elastic scattering in other rare gases with this apparatus proved fruitless, suggesting that in the heavier rare gases the resonances are of smaller magnitude such that they are beyond the detection sensitivity of the apparatus.

III. PRINCIPLE OF THE TRANSMISSION EXPERIMENT

One should be able to observe structure in the elastic cross section with more sensitivity if one studies the electrons transmitted through the gases at relatively high pressure. Generally, the transmitted current is given by the sum of the unscattered current, i_0e^{-NQL}, and by a term giving the contribution of the scattered current.[9] An improvement in sensitivity can be achieved only if the acceptance angle of the collector is limited so that only the unscattered beam is accepted. If we measure only the unscattered portion of the electron current and if the width of the electron energy distribution is smaller than the width of the resonance, then the currents i_1 and i_2 arriving at the collector off resonance and on resonance, respectively, are given by $i_1=i_0e^{-NQ_1L}$ and $i_2=i_0e^{-NQ_2L}$. Taking the ratio and rearranging, we obtain

$$\ln\frac{i_2}{i_1}=NQ_1L\left(\frac{Q_1-Q_2}{Q_1}\right)=NQ_1Lf_0. \qquad (1)$$

Here, i_0 is the current entering the chamber, Q_1 and Q_2 are the cross sections off and on resonance, respectively, N is the gas density and L the length of the chamber. The quantity $f_0=(Q_1-Q_2)/Q_1$ is the "fractional dip" at resonance which would be observed with truly monoenergetic electrous. The width of this resonance would be determined by the natural lifetime of the state and by Doppler broadening.

The width of the resonance is further broadened by the effective electron energy distribution. In a transmission experiment we have to inquire into the cause for the apparent broadening of the electron energy distribution and we distinguish between an energy spread resulting from imperfections "internal" and

[8] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, Inc., New York, 1952).

[9] H. Bartels, Z. Physik **55**, 507 (1929); H. Bartels and H. Noack, *ibid.* **64**, 465 (1930); H. Bartels and C. H. Nordstrom, *ibid.* **68**, 42 (1931).

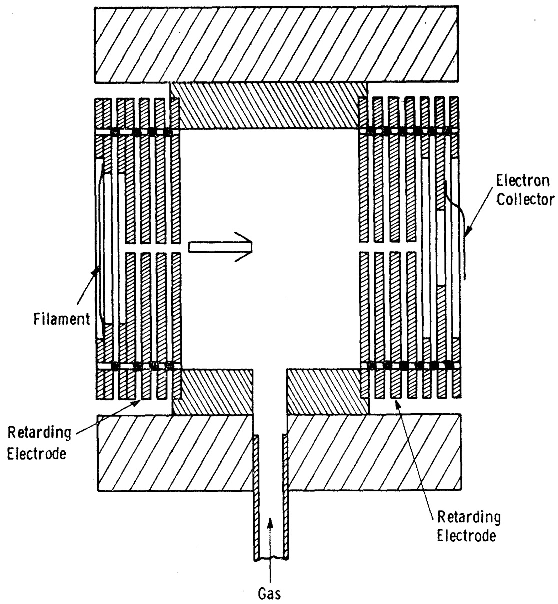

FIG. 2. Diagram of the tube used in the transmission experiment.

"external" to the collision chamber. By "internal" broadening we mean the broadening of the resonance resulting from spatial variations of the electric potential along the path of the electrons in the collision chamber. These variations of the electric potential cause the electrons to speed up and slow down as they travel inside the collision chamber. By "external" broadening we mean the broadening of the resonance resulting from the energy distribution of the electrons as they enter the collision chamber. The external broadening is thus determined by the electrode arrangement and electric-potential variations ahead of the collision chamber. In the following we use oversimplified energy and potential distributions in order to simplify the discussion. A more exact formulation does not help in the present state of these experiments.

Let us first consider the case of *internal* broadening of the resonance line, neglecting external broadening. Let us further assume that the resonance in the cross section is a "square well," of width w_0 and that the fractional dip is f_0, as defined above. We wish to derive the transmitted current i_2, when monoenergetic electrons arrive at the entrance of the collision chamber with an energy equal to the energy of the resonance. Because the electrons experience a potential variation along their path in the collision chamber which brings them alternately "in" and "out" of resonance, the elastic cross section is alternately Q_1 (out of resonance) and Q_2 (in resonance). Thus the elastic cross section $Q(l)$ becomes a function of position l. The current of electrons di, scattered out in a length dl is given by $di=-iNQ(l)dl$. By integration we obtain $\ln i/i_0=-\int_0^L NQ(l)dl$. If the total potential spread along the electron beam is w_i, then the electrons will experience an elastic cross section Q_2 only for a portion of the path length, given approximately by $(w_0/w_i)L$ and a cross section Q_1 for the remainder of their path. We can write

$$\ln i_2/i_0=-\int_0^{(w_0/w_i)L} NQ_2dl-\int_{(w_0/w_i)L}^{L} NQ_1dl$$

$$=-(w_0/w_i)NL(Q_2-Q_1)-NQ_1L\,, \qquad (2)$$

and normalizing to the current "off" resonance, $i_1=i_0e^{-NQ_1L}$, we obtain

$$\ln(i_2/i_1)=NQ_1L(w_0f_0/w_i)\,. \qquad (3)$$

Here w_0 and f_0 are the width and fractional dip, respectively, of the resonance line broadened by natural and Doppler broadening.

Now let us inquire into the additional effect produced by an electron energy distribution generated *external* to the collision chamber. For simplicity, we shall treat a square energy distribution of width w_e. A portion w_i/w_e of the electrons is within the region of resonance and is attenuated by an exponential given by Eq. (2). The remainder of the electrons, $1-(w_i/w_e)$ is completely outside the region of resonance. The current on resonance, i_2, normalized to the current entering the collision chamber i_0 is

$$(i_2/i_0)=(w_i/w_e)\exp[-(w_0/w_i)NL(Q_2-Q_1)-NQ_1L]+[1-(w_i/w_e)]\exp(-NQ_1L)$$

and the ratio of currents on and off resonance becomes

$$\frac{i_2}{i_1}=\left(1-\frac{w_i}{w_e}\right)+\frac{w_i}{w_e}e^{+NQ_1L(w_0/w_i)f_0} \quad \text{for} \quad w_e\geqslant w_i \qquad (4)$$

For $w_e=w_i$ Eq. (4) is identical to Eq. (3).

We can summarize the results of our considerations. When nonuniformities internal to the collision chamber predominate, electrons change their kinetic energy as a function of position; individual electrons do not maintain their energy relationship with respect to the resonance so that electrons with energies outside the resonance do not get preferentially treated. On the other hand, when the energy distribution generated external to the collision chamber dominates, electrons maintain their initial energy relative to the resonance in the absence of space-charge effects and those electrons lying outside the resonance get preferential treatment. In the case of the 19.3-eV helium resonance, electrons outside the resonance get preferentially attenuated. A numerical example best illustrates the enormous difference in the ratio of current on and off resonance in the two cases treated above. Assume some values attainable in a transmission experiment involving the helium resonance, namely $w_0f_0=0.01$ eV, $NQ_1L=10$, and the measured half-width of the resonance 0.15 eV. If the width of the resonance is a result of "internal" causes we obtain, using Eq. (3), $i_2/i_1=e^{0.1/0.15}=1.95$. If, however, this same broadening of 0.15 eV had been due to "external" causes only, Eq. (4) yields (by substituting $w_e=0.15$ eV; $w_i=w_0\approx 0.03$ eV) $i_2/i_1\approx 6.3$. Clearly, the ratio of the currents on resonance to the current off resonance is much larger in case the resonance is broadened by external effects than if it is broadened by internal effects. In both cases, however, an enhancement of the resonance results from use of the transmission method compared to the scattering experiments of Secs. I and II. These considerations may prove to be useful for an analysis of the causes for the energy spread in electron-beam experiments.

It should be noted that if the restriction of a limited acceptance angle is removed, and the scattered current is allowed to enter the collecting system, the current arriving at the collector in the limit of high pressures is proportional[9] to $(NQL)^{-1}$, and thus no amplification of the resonance is expected.

The above considerations shed light on the discrepancy between the original experiment of Maier-Leibnitz[10] who studied the electrons transmitted through helium (with the purpose of obtaining the inelastic cross section) and did not observe the 19.3-eV resonance and the experiment of Fleming and Higginson[5] who observed the resonance[11] in a modified Maier-Leibnitz apparatus. Whereas Maier-Leibnitz used an open collecting system, Fleming and Higginson worked in parallel-plate geometry and had a limiting exit aperture. This fact accounts for the enhancement of the resonance in the experiments of Fleming and Higginson.[12]

In the experiment described in the following section, discrimination against the scattered electrons is achieved by a retarding potential at the output of the collision chamber as well as a limiting exit aperture.

IV. EXPERIMENTAL ARRANGEMENT OF THE TRANSMISSION EXPERIMENT

A diagram of the tube used in the transmission experiment is shown in Fig. 2. Electrons from a thoria-coated iridium filament are aligned by an axial magnetic field and traverse the first three plates constituting the electrodes for use with the retarding-potential-difference method.[13] The electrons are then accelerated into the high-pressure (~0.3 Torr) collision chamber. The electrons leaving the collision chamber are decelerated to nearly zero energy and collected on the electron collector. The deceleration at the output enables us to discriminate against the scattered beam because this class of electrons has their velocity vector reoriented and thus only a small portion of these electrons can reach the collector. This discrimination, in favor of the unscattered electrons, is further aided at the higher pressures and in the light gases by the energy loss resulting from elastic scattering. The decrease in collected current with gas pressure is approximately exponential[14] and this is taken as an indication that Eq. (3) is approximately valid under the present experimental conditions.

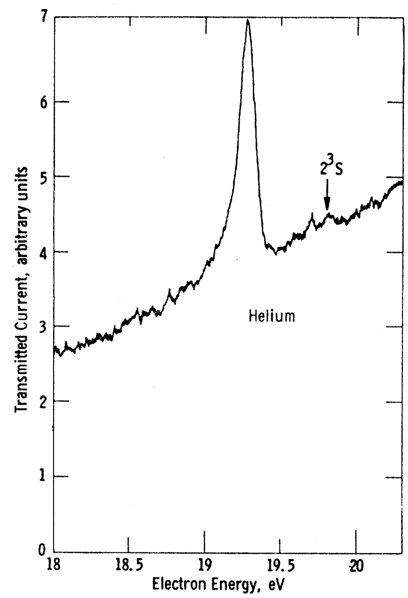

FIG. 3. Transmitted current versus electron energy in helium at a pressure of 0.66 Torr. The arrow points to the position of the first electronically excited state. The curve is a tracing obtained on an X–Y recorder.

The tube shown in Fig. 2 is assembled using 1.5-mm-diam sapphire spheres as spacers between electrodes. All electrodes have six equidistant holes drilled on a common circle; three of these holes are used for each set of plates. The two plates adjoining the electron collector serve as guard plates and are maintained at the potential of the electron collector (ground potential). The whole plate assembly is held together with spring-loaded end plates. The length of the collision chamber is 1.5 cm. All electrodes are gold-plated. The tube is baked at 400°C, and a liquid nitrogen trap provides isolation from the 200-liter/sec mercury pump. A high-pressure ionization guage[15] is used for pressure measurements.

The tube has been operated in both the dc and ac

[10] H. Maier-Leibnitz, Z. Physik **95**, 499 (1935).

[11] Fleming and Higginson (Ref. 5) worked at $NQL\sim 5.0$ and with an energy distribution around 0.5 eV. This leads from Eq. (3) to $i_2/i_1=1.1$, i.e., a 10% rise in the current. Their observed rise was 6%. The discrepancy is partially due to the fact that a portion of the scattered current is admitted to their electron collector.

[12] R. J. Fleming [thesis, The Queen's University of Belfast, 1962 (unpublished)] observed a decrease in the magnitude of the resonance with increasing exit-hole diameter. Although he attributed this effect to field penetration, it is suggested that the decrease in the magnitude of the resonance is due to the increasing importance of the scattered electrons.

[13] R. E. Fox, W. M. Hickam, D. J. Grove, and T. Kjeldaas, Rev. Sci. Instr. **26**, 1101 (1955).

[14] The best exponential is obtained in H_2 and the largest deviations are observed in Xe.

[15] G. J. Schulz and A. V. Phelps, Rev. Sci. Instr. **28**, 1051 (1957).

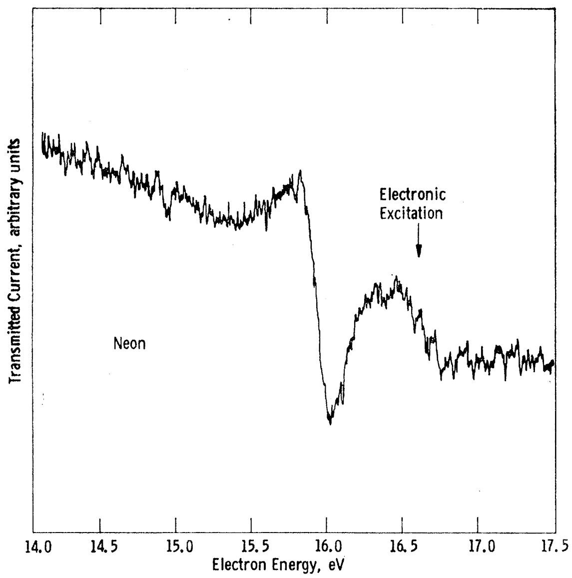

FIG. 4. Energy dependence of transmitted current in neon in the vicinity of the resonance. The vertical scale is distended.

modes; the results are identical. In the dc operation, a vibrating-reed electrometer is used for measuring the transmitted electron current and the potential on the entrance retarding plate is altered manually. In searching for resonances the ac system is used. A square wave about 0.1 V is applied to the entrance retarding electrode at a frequency about 17 cps and a sensitive preamplifier[16] is used for measuring the collector current. The ac signal resulting from the modulated difference current is then amplified, synchronously detected and exhibited on the Y axis of an X–Y recorder.[17] The X axis is the electron accelerating voltage, supplied by a motor-driven potentiometer. The data obtained in this manner are shown in Figs. 3, 4, 5, and 6.

The measured half-width of the resonance in helium without use of the retarding-potential-difference method is 0.30 eV and it reaches a limiting value of 0.15 eV by use of the retarding-potential-difference method. The experimental results suggest that this limiting energy distribution is caused by nonuniformities in the collision chamber[18] and thus the half-width of 0.15 eV should be associated with the quantity w_i, defined in Sec. III.

V. RESULTS OF THE TRANSMISSION EXPERIMENT IN HELIUM

Figure 3 shows the transmitted current as a function of electron energy in helium. The figure is a tracing of the curve as it is taken on the X–Y recorder. The drop of the cross section around 19.3 eV is now observed as an increase in transmitted current. In this curve the zero is not suppressed, and it is immediately obvious that the enhancement of the resonance, postulated in Sec. III, is present. The ratio of the current transmitted on resonance to that off resonance (18.5 eV) is 2.3, an enhancement by a considerable factor from the 14% observed in the scattering experiment. Comparing Fig. 3 with Fig. 1 we notice several minor differences. The half-width of the transmitted peak of Fig. 3 is broadened to 0.15 eV, as expected from the broader electron energy distribution. The rise in cross section subsequent to the dip, so pronounced in Fig. 1, is almost absent in Fig. 3. This also results from the poorer electron energy distribution. Observation of this structure is probably a very sensitive test of the electron energy distribution because of the competition from the main resonance in the cross section. The small decrease in transmitted current at 19.8 eV (marked with an arrow) is due to the onset of the inelastic process at this energy. If all the exit plates after the collision chamber are made positive ($\sim$+4 V) with respect to the entrance retarding plate in order to admit a portion of the scattered electrons, this dip becomes very pronounced and the total inelastic cross section is traced out. Such a plot, using the dc method is shown in Fig. 7. This curve is similar to that obtained by Fleming and Higginson.

If we now plot the ratio of the current at 19.3 eV to the current at 18.5 eV, against the collision number NQ_1L, we obtain the plot shown in Fig. 8. Here the closed circles are obtained with the retarding-potential-difference method, i.e., with an energy spread, $w_i=0.15$ eV. The open circles are obtained without use of the

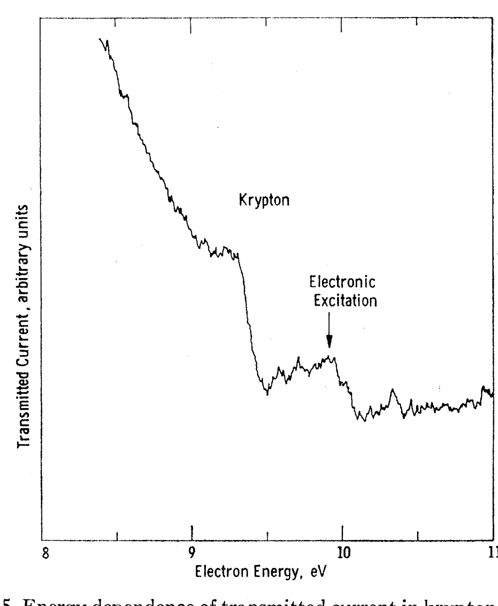

FIG. 5. Energy dependence of transmitted current in krypton in the vicinity of the resonance. The vertical scale is distended.

[16] The author is indebted to R. W. Warren and J. H. Parker for the loan of their preamplifier [see H. J. Parker and R. W. Warren, Rev. Sci. Instr. **33**, 948 (1962)] and assistance with the associated circuitry.

[17] The ac method has been used previously. See G. J. Schulz, J. Chem. Phys. **33**, 1661 (1960).

[18] After demounting of the tube it was found that some of the gold-plated surfaces had been coated with mercury from the diffusion pump. It is possible that this caused the large residual energy spread.

retarding-potential-difference method, i.e., with an energy spread of 0.3 eV ($w_e/w_i=2.0$).

Although there is considerable scatter in the points, a straight line is drawn through the closed circles. By using Eq. (3) and correcting for the fact that the ratio i_2/i_1 of Fig. 8 is taken at two different energies (this correction is approximately 20%), we obtain values for the product $w_0 f_0$ of 0.011 eV. This compares with a corresponding value $w_0 f_0=0.14\times 0.06=0.0084$ eV from the scattering experiment. The discrepancy of less than 20% is not considered to be particularly significant at this time because of the experimental uncertainties, although one could argue that it is due to the different angle of observation. Such considerations will have to await an experiment on the angular variation of the cross section near the resonance.

The dashed line of Fig. 8 is obtained using Eq. (4) with the parameter $w_e/w_i=2.0$, $w_0 f_0=0.011$ eV, and $w_i=0.15$. The agreement is seen to be good.

VI. RESULTS IN Ne, Kr, Xe

Figures 4, 5, and 6 show the results of the transmission experiment in neon, krypton, and xenon. On all these tracings the zero is suppressed so as to show the resonances clearly. The resonances are superimposed on the variations of the elastic cross sections in the energy range shown. Because the energy dependence of the elastic cross sections is much more pronounced than in the case of helium, the exact shape of the resonance cannot be clearly extricated.

In neon, it appears that the transmitted current first rises and subsequently drops, the rise and fall being roughly symmetrical. This is in complete agreement with Fig. 1, realizing that a rise in transmitted current corresponds to a decrease in the cross section. Past 16.6 eV, electronic excitation causes a drop in the transmitted current. Because of the heavy mass of neon in comparison with helium, the suppression of the scattered electrons is not complete here and the effects of scattered electrons including excitation are expected to be evident. The region in which structure occurs extends over about 0.7 eV, far larger than the energy spread of the electron beam. Thus it seems that the resonance is much broader and thus the lifetime of the compound state shorter than in helium. Simpson and Fano[6] have found two sharp decreases in transmission around 16.0 eV. This structure

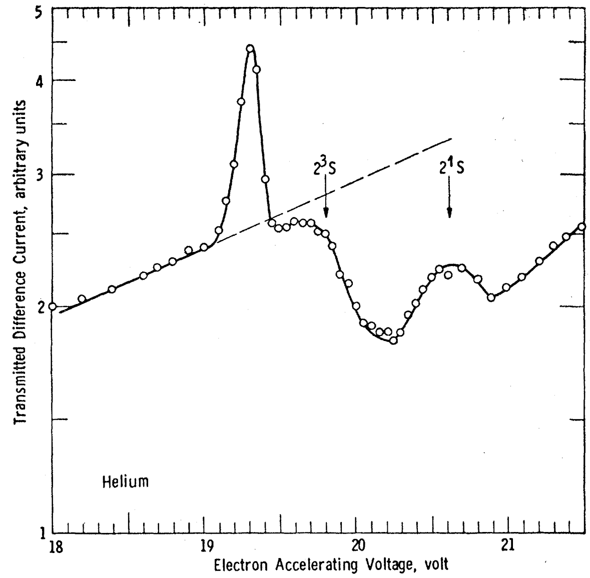

FIG. 7. Transmitted current versus electron accelerating voltage in helium with exit electrodes at +4.0 V with respect to the entrance retarding electrode. The peak at 19.3 eV results from the resonance in the elastic scattering. The decrease above 19.8 eV is due to inelastically scattered electrons (2^3S and 2^1S levels).

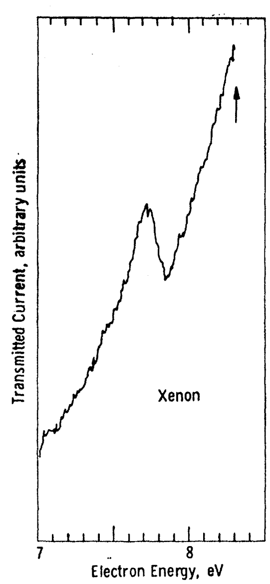

FIG. 6. Energy dependence of transmitted current in xenon in the vicinity of the resonance. The vertical scale is distended.

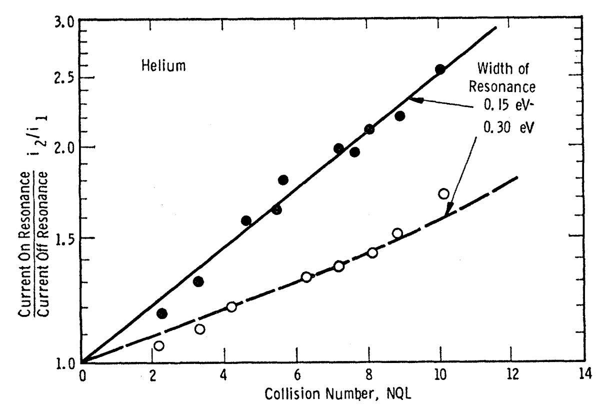

FIG. 8. Ratio of the transmitted current at 19.3 eV (on resonance) to the current at 18.5 eV (off resonance) as a function of collision number. The closed circles are obtained using the retarding-potential-difference method (half-width ~0.15 eV) and the open circles are obtained without use of the retarding-potential method (half-width ~0.30 eV). A straight line is drawn through the closed points [see Eq. (3)]. The dashed line is a plot of Eq. (4) using $w_i=0.15$ and $w_e/w_i=2.0$.

could not be resolved in the present experiment because of lack of resolution.

VII. CONCLUSIONS

The experiments described in this paper show that resonances in the elastic cross section of the rare gases studied occur around 0.5 eV below the first electronically excited state of the respective atoms. The magnitude of these resonances decreases with increasing atomic weight.

The relationship between observation of these resonances in scattering experiments, where the cross-section behavior is observed directly, and transmission experiments, where the structure in the attenuated beam is observed, is now understood and confirmed by experiment. When one observes only the unscattered portion of the electron beam in transmission, the structure in the vicinity of the resonance is enhanced. On the other hand, when the scattered current is the predominant component of the electron current, no enhancement will result. This observation explains the discrepancy existing between two experiments on the transmission of electrons in helium.[5,10]

The product of the width of the resonance and the fractional change in cross section in helium is found to be about 0.01 eV. Thus, if the cross section reaches zero, the width would be approximately 0.01 eV. This conclusion is in agreement with that of Simpson and Fano.[6] However, in the heavier rare gases the resonances are broader and not limited by the electron energy distribution. In these gases the structure is less than 3% and thus it is improbable that these resonances reach the theoretical maximum or zero, as is the case in nuclear resonances.[8]

It should be pointed out that the resonance in helium provides a much needed calibration point not only for the energy scale in electron-beam experiments, but also for the electron energy distribution.[19] In addition, the considerations of Sec. III show that one can now obtain an indication of the cause of the electron energy distribution, i.e., a separation between the energy distribution broadening due to effects inside and outside the collision chamber. This can be done by comparing the measured ratio of currents on and off resonance with Eqs. (3) and (4), respectively. Such a procedure will facilitate the use of monoenergetic electron-beam techniques.

It is also evident from the considerations of Sec. III that the energy distribution of electrons around 19.3 eV can be sharpened by transmitting them through helium gas at high pressures, provided that the nonuniformities in contact potential within the chamber are small.

ACKNOWLEDGMENTS

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[19] It is well known that retarding curves for obtaining the energy distribution are very unreliable when the retarding is done near surfaces and although the reliability improves when the retarding is done in space, it is suggested that the helium resonance provides a much more reliable tool for such measurements.