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Elastic Scattering of Electrons by Mercury Atoms

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The angular distribution of electrons elastically scattered by single mercury atoms was studied for electrons of 10 to 800 volts energy, and in an angle range of 5° to 172°. The values of the atomic scattering coefficient, P_θ (the number of electrons scattered per atom, per unit electron current density, per unit solid angle at an angle θ to the original beam) have been computed from the observed scattered currents. New maxima were found in the angle range between 120° and 172°. Practically all of the curves indicate that the value of P_θ rises to a relatively large maximum at or near 180°.

THE scattering of slow electrons by single gas atoms has been studied by a number of observers. Arnot[1] was the first to observe maxima and minima in the scattered current from mercury atoms. These maxima and minima have been interpreted as a diffraction pattern of the electron waves. Arnot's measurements extended from 8.6 volts to 800 volts and in angle from 18° to 126°. Pearson and Arnquist[2] also found these maxima and minima for velocities between 100 and 200 volts in the angle range between 30° and 100°. Tate and Palmer[3] have repeated Arnot's measurements for electron energies of 80, 120, 230, 490 and 700 volts and in an angle range of 5° to 123°. They also studied the inelastic as well as the elastic scattering. In the measurements reported in this paper, electrons of 10 to 800 volts energy were used and the angle range extended from 5° to 172°.

APPARATUS

The metal parts of the apparatus were made of tantalum, spot-welded together. Tantalum was used because it is nonmagnetic and easy to spot-weld. The electron gun consisted of a cylinder with a 4 mil tungsten filament along its axis. A slit 0.2 mm in width and 2 mm in height let through a fine beam of electrons. At voltages above the ionization potential of mercury, the beam, because of space charge, remained very narrow even at considerable distances from the slit. The collector consisted of a Faraday cylinder 6 cm long. It was supported by a long tungsten rod sealed in Pyrex glass. No trouble was experienced from leakage currents to the pliotron grid. The collector was surrounded by a grounded cylinder. All cylinders were insulated from each other by means of Pyrex glass tubing.

The scattered electrons from the beam entered the collector through 4 slits, as shown in Fig. 1.

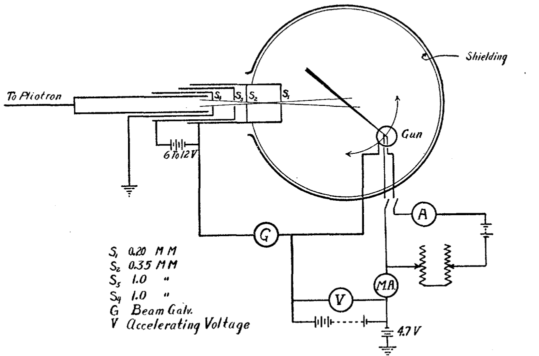

FIG. 1. Scattering apparatus with electrical circuit.

The first two slits were always at the same potential as the outer cylinder of the electron gun and the cylindrical metal box which entirely enclosed the scattering region. These first two slits determine the volume of the scattering space from which the electrons were collected. The other diaphragms were used to keep out positive ions and electrons which were inelastically scattered from the mercury atoms.

MEASUREMENTS

The position of the electron gun was changed relative to the collector by the rotation of a

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[1] F. L. Arnot, Proc. Roy. Soc. **A130**, 655 (1931).

[2] J. T. Tate and R. R. Palmer, Phys. Rev. **40**, 731 (1932).

[3] J. M. Pearson and W. N. Arnquist, Phys. Rev. **37**, 970 (1931).

ground glass joint to which the gun was attached. Considerable care was taken to make the axis of rotation of the gun the point of intersection of the stream of electrons from the gun and the axis of the collector slit system. If the beams did not intersect in this center of rotation, the scattered current intensities on the two sides of the central beam were not symmetrical. When this adjustment is properly made the scattering is identical on both sides.

The sensitivities of the galvanometers were measured with every set of observations. The resistances were measured at frequent intervals throughout the period of several months in which the measurements were made. The galvanometer used in measuring the electron beam current was adjusted by means of shunts to a sensitivity of approximately 10^{-7} amperes per mm. The limit on the magnitude of the beam current is set by the small intensity of the scattered current.

Arnot[1] and Tate and Palmer[2] used an electrometer to measure the scattered currents. In the measurements reported in this paper a vacuum tube electrometer (General Electric F P 54) was used. The circuit for the vacuum tube electrometer is shown in Fig. 2. The resistance *HR* was a composite resistance purchased from the S. S. White Dental Mfg. Co. and was of the order of magnitude of 6×10^{10} ohms.

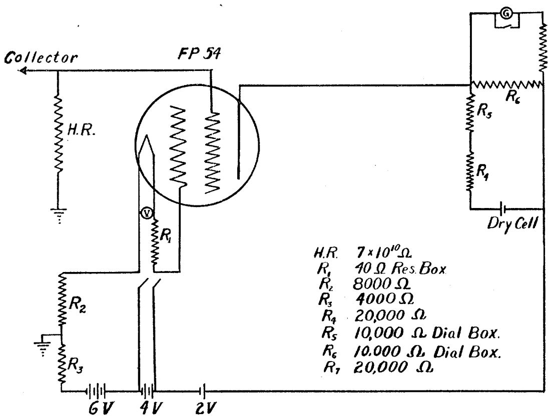

FIG. 2. Vacuum tube electrometer circuit.

The sensitivity of the system could be adjusted by varying the shunt resistance *R* in the galvanometer circuit. It was usually adjusted to a sensitivity of about 5.0×10^{-16} amperes per scale division. The deflections were steady and could be repeated. The zero shift was small.

NOTATION

The scattering of electrons by atoms is measured by the electron current scattered in a unit solid angle by a single atom placed in a stream of unit electron current density. The angle of scattering is measured between the direction of the initial electron current and the scattered electron current. The atomic scattering coefficient P_θ, may be expressed as the scattered electron current, per atom, per unit electron current, per unit solid angle in the direction θ.

The results of many measurements are expressed in values of the scattered electron current, per unit electron current, per unit solid angle in the direction θ, per unit path length, per unit pressure at 0°C. This scattering coefficient, S_θ, is related to the above defined atomic scattering coefficient P_θ by the relation $S_\theta = P_\theta n$, where n is the number of atoms per cc, at unit pressure and at 0°C. If the unit of pressure is 1 mm of Hg, n is 3.56×10^{16}.

To convert the above scattered currents into these scattering coefficients it is necessary to know the solid angle effective for collection of the electrons as defined by the geometry of the apparatus. Arnot made his calculation on the assumption that the solid angle is given by the angle between the two extreme rays entering the Faraday cylinder in the horizontal plane multiplied by the angle between the two extreme rays in the vertical plane. Tate and Palmer observed the total scattered current and multiplied it by an arbitrary constant so as to bring their values into agreement with measurements of the total scattered currents made previously by Palmer.

The scattered current I_θ and the initial beam current I_0 are related to P_θ by the equation $I_\theta/I_0 = P_\theta n \int \omega dx$. Where n is the number of atoms per unit volume, ω the solid angle effective in collecting electrons at any point along the beam and dx is the element of length along the beam. The integration is over all parts of the beam for which ω is not 0. For angles between 5° and 175° and for beam and slit sizes used in these experiments the $\int \omega dx$ is quite accurately given by the expression $abh/[A(A-B)\sin\theta]$, where a is the width of the defining slit near the Faraday cylinder and A its distance from the beam, b the width of the defining slit near the beam and B its distance from the beam, h the height of slit a and θ the angle between the beam and the axis of the collecting slit system. The numerical value of this factor for the apparatus used in this experiment is 7.3×10^{-5} cm. Arnot's calculation of the solid angle is a function of the height of the electron beam while the above calculation shows that the height of the beam is not important as long as the beam is not large in comparison with the height of the slits.

RESULTS

The results of the measurements are given in Figs. 3 to 8.

The previous measurements of Arnot and Tate and Palmer agree in general in the shapes of the curves and number of maxima and minima in the region of their measurements, i.e., from 5° to 120°. In the region 120° to 170° new maxima are found. The intensity of the scattered currents in the direction backwards from the initial direction of the electron beam is for many velocities quite appreciable.

The magnitudes of the observed currents differ considerably in the three sets of measurements to be compared. Although the solid angle of collection in Arnot's apparatus was nearly the same as in this apparatus, the magnitude of the scattered currents in his experiment is about 3 times the scattered currents in these measurements, for the same initial beam current, at the same pressure. Tate and Palmer do not give the magnitude of their scattered currents. The discrepencies in these magnitudes are larger than would have been anticipated from the rather good agreement in the shapes of these curves.

Arnot estimated that his solid angle was probably correct to within 50 percent. Because of this and the disagreement in the magnitudes of the results in this field, the magnitudes of P_θ in the Figs. 3 to 7 have been labeled P_θ in arbitrary units. The relative values of the magnitudes of P_θ are however believed to be quite precise.

Errors in the measurements of temperature and consequently the vapor pressure might cause some of the difference. The measurement and alignment of the slits of the collectors which enter into the calculation of the effective solid angle may also be a possible source of error. Errors may enter into the estimate of the effective solid angle when retarding potentials are applied between the defining slits or if the retarding field pene-

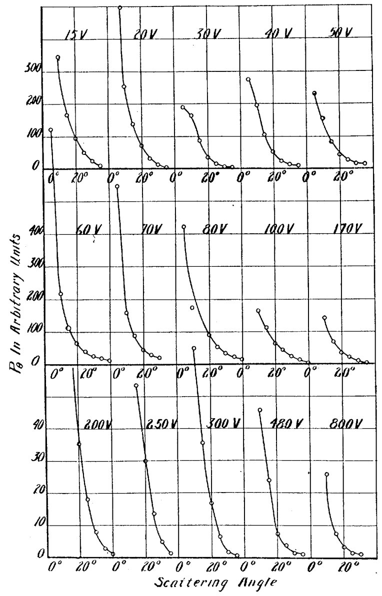

FIG. 3. Atomic scattering coefficient, P_θ, for small angles.

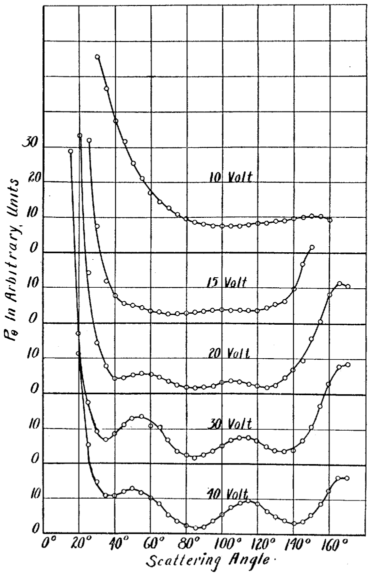

FIG. 4. Atomic scattering coefficient, P_θ.

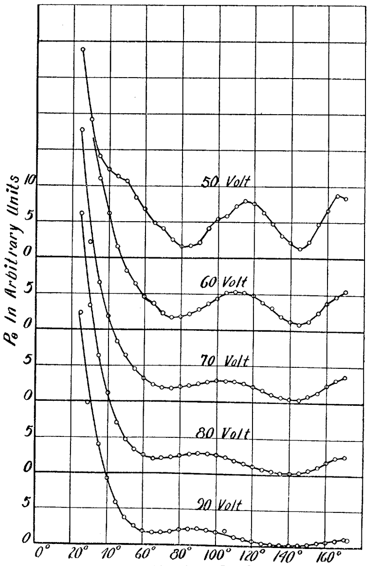

FIG. 5. Atomic scattering coefficient, P_θ.

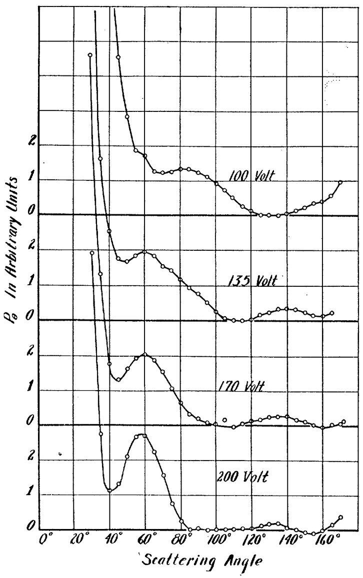

FIG. 6. Atomic scattering coefficient, P_θ.

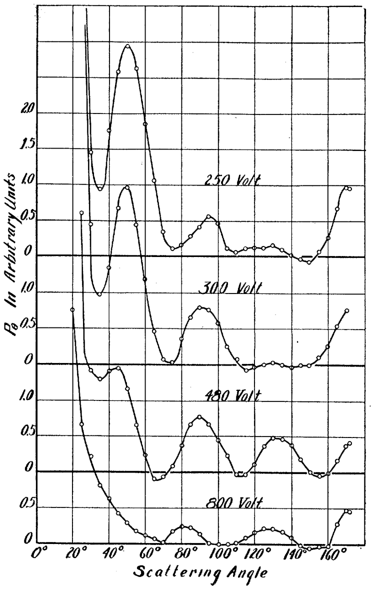

FIG. 7. Atomic scattering coefficient, P_θ.

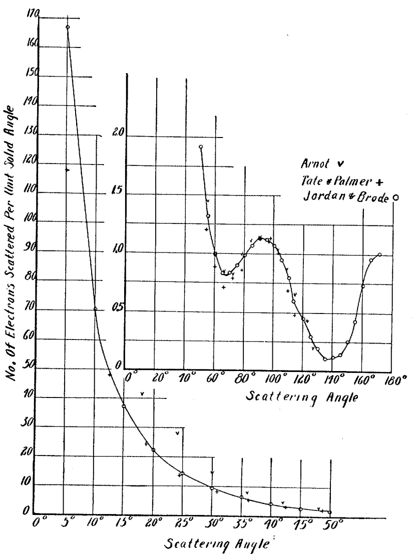

FIG. 8. Number of elastically scattered electrons per unit solid angle per cm path length, per mm of Hg pressure at 0°C, per unit electron current, as a function of angle, for 80 volt electrons.

trates one of the defining slits. Precautions were taken to prevent this by the insertion of extra slits, between which the retarding potentials were applied.

By using a long Faraday collector with no potential difference between it and the slit nearest to it, errors due to the positive ions produced in the chamber were reduced so that negative currents were observed only for the higher voltages and then only very slightly more than the probable error in the measurements. A comparison of the observations of Arnot, Tate and Palmer and those reported here are shown in Fig. 8 for 80 volt electrons. The magnitudes of the data have been adjusted so that the curves are in agreement at 90°. The scale of the ordinate has been chosen to agree with the magnitudes given by Tate and Palmer for the number of electrons scattered per unit solid angle per cm of path per unit pressure at 0°C. The observed values are in excellent agreement with those of Tate and Palmer.

While these measurements were being prepared for publication, a brief note by Arnot[4] appeared, reporting similar measurements to those reported here. Arnot calls attention to the pronounced backward scattering of electrons with from 10 to 50 volts energy. The curves in this preliminary report of Arnot's are in fair agreement with those reported here.

In another brief preliminary note Henneberg[5] has calculated the values of P_θ for the elastic scattering of 135, 480 and 800 volt electrons by mercury atoms. Henneberg predicted the relatively large backward scattering which has been observed in these measurements. The number of maxima and their positions and relative magnitudes are only in approximate agreement with the observed curves. The disagreement between the theoretical and experimental curves does not appear to be very important as it can probably be accounted for by approximations made in finding the potential field of the scattering mercury atom.

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[4] F. L. Arnot, Nature **130**, 438 (1932).

[5] W. Henneberg, Naturwiss. **30**, 561 (1932).