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LETTER TO THE EDITOR

Elastic scattering of low-energy electrons by neon atoms

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Abstract. Differential elastic scattering of electrons at 7.5, 10, 12.5, 15, 17.5 and 20 eV from neon is reported. The s, p, d and f phaseshifts derived from the measured cross sections are also presented.

In this letter we report new absolute differential cross sections (DCS) for the elastic scattering of electrons from neon atoms at incident electron energies (E) of 7.5–20 eV and for scattering angles of 20–120°.

The first experimental measurements of the angular distributions of electrons scattered elastically from neon atoms were made in the early 1930s by Ramsauer and Kollath (1932), Bullard and Massey (1931a, b) and Hughes and McMillen (1933). A period of some thirty years elapsed before further measurements were made by Mehr (1967) at 10 eV only and later by Andrick and Bitsch in 1973 (unpublished but quoted in part by Andrick (1973) and by Andrick (1978) in a private communication), Williams (1979) and the present work. Other workers have investigated higher energy scattering or have made measurements at only one energy less than 20 eV. McConkey and Preston (1973) presented some preliminary results and Williams and Crowe (1975) have reported data at 20 eV, which is the upper limit of the present measurements. Excepting the 1930s work and the single energy measurements at 10 and 20 eV, only the unpublished data of Andrick (1978) gives a range of differential cross section values for $E \leqslant 20$ eV. Unfortunately Williams' data is only available in the form of derived phaseshifts and therefore no comments can be made about his differential cross section measurements.

The apparatus, experimental procedures and the method of performing the phaseshift analysis have been given in detail by Newell *et al* (1981) (hereafter referred to as I) and will not be repeated here. The computer program used in the phaseshift analysis was supplied by Gibson (1980) and used by Gibson and Rees (1976) in analysis of argon differential cross sections.

The relative DCS obtained from the present experiments were first normalised to the experimental data of Andrick (1978) prior to performing the phaseshift analysis. Where the value of E (7.5, 12.5 and 17.5 eV) did not correspond to a measurement made by

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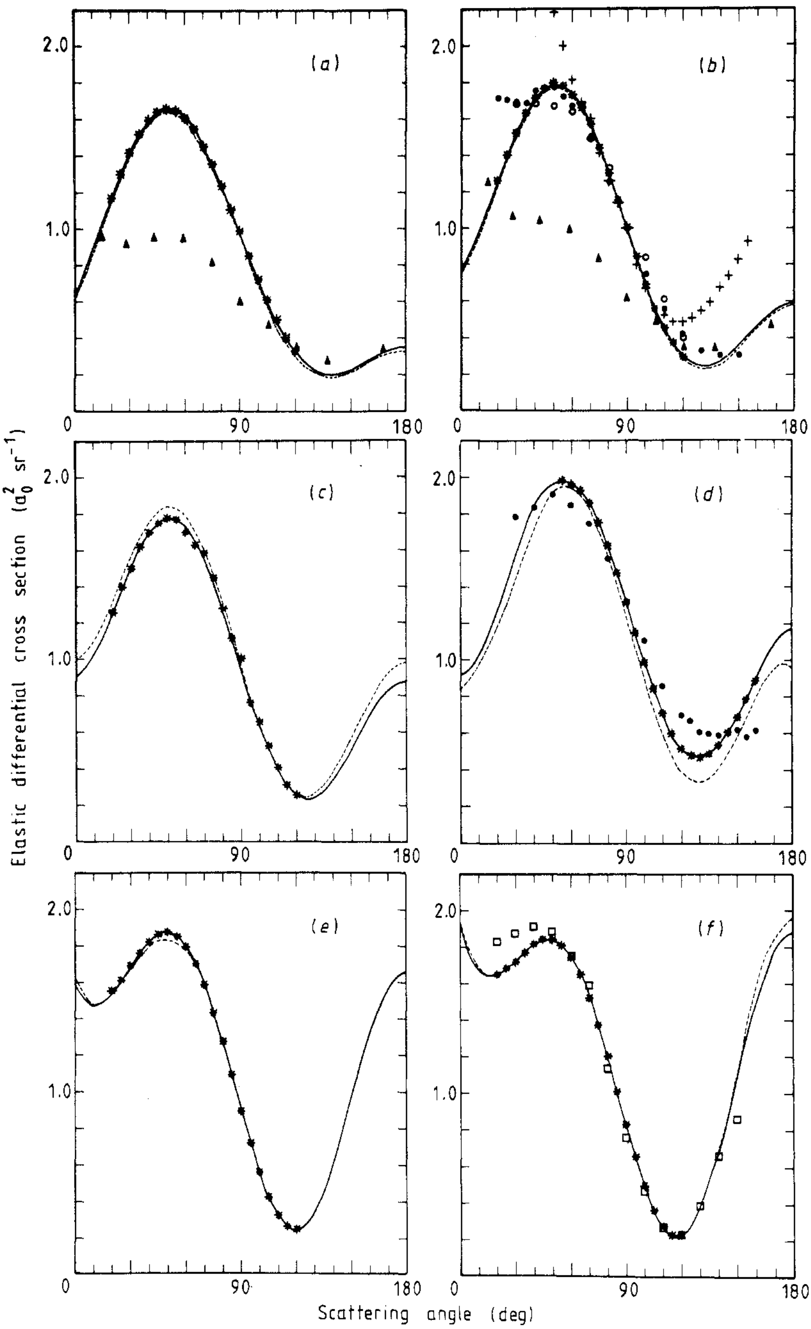

Figure 1. Differential cross sections for the elastic scattering of electrons from neon. *, present measurements; ———, phaseshift fit to the present measurements; ○, Bullard and Massey (1931a, b); ▲, Ramsauer and Kollath (1932); ●, Hughes and McMillen (1933); +, Mehr (1967); □, Williams and Crowe (1975); - - - -, Andrick (1978). The relative data of Bullard and Massey and Hughes and McMillen have been normalised to the present measurements at $\theta = 90$ degrees. (*a*) $E = 7.5$ eV. The measurements of Ramsauer and Kollath were made at 7.9 eV and Andrick's were made at 8 eV. (*b*) $E = 10.0$ eV. The measurements of Ramsauer and Kollath were made at 10.4 eV; all others were made at 10.0 eV. (*c*) $E = 12.5$ eV. Andrick's measurements were made at 13 eV. (*d*) $E = 15.0$ eV. (*e*) $E = 17.5$ eV. Andrick's measurements were made at 18 eV. (*f*) $E = 20.0$ eV.

Andrick, normalisation was made to the next lowest value of E that he used (7, 12 and 17 eV). The normalised cross section values for $E = 10$, 12.5, 17.5 and 20 eV were rescaled by Gibson and Rees' program by less than 2% whereas the cross section measurements at 7.5 and 15 eV were rescaled by 6 and 7% respectively. These rescaled values (i.e., $\lambda \neq 1$) are plotted in figure 1 and are tabulated in table 1 together with the estimated total error for each data point. Since Andrick presented his data in the form of derived DCS calculated from derived phaseshifts (his original experimental values were not tabulated), his data in figure 1 are shown as a broken curve extending from 0 to 180°. Other data in figure 1 include that of Ramsauer and Kollath (7.9, 10.4 eV), Bullard and Massey normalised to the present results at 90° (10 eV), Hughes and McMillen also normalised to the present results at 90° (10, 15 eV), Mehr (10 eV) and Williams and Crowe (20 eV). There is excellent agreement between the present data at $E = 7.5$, 10, 17.5 and 20 eV and the data of Andrick at 8, 10, 18 and 20 eV respectively. The agreement at $E = 12.5$ and 15 eV with Andrick's data at 13 and 15 eV is less good, with the greater discrepancy occurring at 15 eV. There is, however, substantial disagreement between the present work and the data of Ramsauer and Kollath (7.9 and 10.4 eV), while the data of Bullard and Massey (10 eV) and Hughes and McMillen (10, 15 eV) exhibit the effects of poor angular resolution, more so at 15 eV than at 10 eV. The more recent data of Mehr (10 eV) only show a vague resemblance to the present data. The measurements made by Williams and Crowe at 20 eV were made using crossed electron and modulated atomic beams and with the intensity of the primary

Table 1. e^-–Ne elastic differential cross sections. Values are in units of $a_0^2\ sr^{-1}$ and represent the absolute cross section value as normalised by the phaseshift analysis. Values in parentheses are the estimated uncertainties in the least significant digit of the cross section.

θ (deg)	Incident electron energy (eV) 7.5	10.0	12.5	15.0	17.5	20.0
20	1.17 (5)	1.26 (5)	1.26 (5)	1.31 (5)	1.55 (6)	1.65 (7)
25	1.30 (6)	1.40 (6)	1.40 (6)	1.41 (6)	1.61 (7)	1.68 (7)
30	1.42 (6)	1.52 (6)	1.50 (6)	1.51 (6)	1.69 (7)	1.72 (7)
35	1.52 (7)	1.63 (7)	1.62 (7)	1.59 (6)	1.76 (7)	1.77 (8)
40	1.60 (7)	1.71 (7)	1.70 (7)	1.66 (7)	1.82 (8)	1.82 (8)
45	1.64 (7)	1.77 (7)	1.75 (8)	1.71 (7)	1.86 (8)	1.84 (8)
50	1.66 (7)	1.79 (8)	1.78 (9)	1.73 (7)	1.87 (8)	1.84 (8)
55	1.65 (7)	1.78 (8)	1.77 (10)	1.72 (7)	1.85 (8)	1.81 (9)
60	1.61 (7)	1.73 (8)	1.70 (10)	1.68 (7)	1.79 (8)	1.74 (9)
65	1.55 (7)	1.66 (8)	1.63 (12)	1.60 (7)	1.70 (7)	1.65 (10)
70	1.46 (9)	1.57 (8)	1.59 (13)	1.49 (6)	1.58 (7)	1.52 (8)
75	1.36 (9)	1.44 (8)	1.45 (10)	1.36 (6)	1.43 (6)	1.37 (7)
80	1.24 (9)	1.30 (7)	1.28 (11)	1.21 (5)	1.27 (5)	1.20 (6)
85	1.11 (9)	1.15 (6)	1.12 (10)	1.05 (5)	1.09 (5)	1.02 (5)
90	0.988 (78)	1.00 (6)	1.01 (8)	0.883 (36)	0.898 (36)	0.829 (34)
95	0.852 (55)	0.844 (51)	0.763 (60)	0.721 (29)	0.718 (29)	0.654 (27)
100	0.727 (34)	0.696 (32)	0.554 (30)	0.574 (23)	0.563 (23)	0.492 (20)
105	0.609 (25)	0.566 (24)	0.525 (25)	0.445 (18)	0.426 (17)	0.364 (15)
110	0.504 (21)	0.455 (19)	0.402 (17)	0.342 (14)	0.325 (13)	0.275 (11)
115	0.408 (17)	0.375 (15)	0.315 (13)	0.272 (11)	0.263 (11)	0.229 (9)
120	0.333 (13)	0.296 (12)	0.262 (11)	0.239 (9)	0.249 (10)	0.232 (9)
125	—	—	—	0.216 (9)	—	—
λ	1.06	1.01	0.98	0.93	1.01	1.00

electron beam monitored using a Faraday cup located at $\theta = 0$. When compared with Andrick's data and the present data their results show a marked disagreement for $\theta < 50°$, whereas for larger scattering angles the agreement is much better. It is possible that the initial higher values of Williams and Crowe are caused by electrons scattered out of their Faraday cup (see Steph *et al* 1979).

A more exacting comparison of experiment and theory can be made by comparing the phaseshifts derived from the DCS with calculated values. The results of the present phaseshift analysis are shown in table 2. In general, the number of phaseshifts required to give the best fit to the present experimental data is reasonably small, indicating the validity of the experimental data and the theoretical equation fitted (equation (18) in I). The phaseshift analysis treatment is, however, technically invalid for fitting the $E =$ 17.5 and 20 eV data because it is assumed that the phaseshifts are real quantities, an assumption which is not valid above the first inelastic threshold (16.11 eV in neon) where they are complex. The values of $P_{\min}$ (see table 2 and equation (19) in I) indicate that the treatment is, however, quite suitable in the case of neon for $16 < E < 20$ eV when the imaginary contribution to the phaseshifts is neglected.

Table 2. e^-–Ne phaseshifts, total cross section $\sigma_t(E)$ and momentum transfer cross section $\sigma_m(E)$. Values for all parameters were derived from the phaseshift analysis of the present DCS measurements.

	Incident electron energy (eV)					
	7.5	10.0	12.5	15.0	17.5	20.0
Phaseshifts						
s wave (deg)	−39.057	−46.148	−50.776	−54.536	−62.792	−66.651
(rad)	−0.6816	−0.8054	−0.8861	−0.9518	−1.095	−1.163
p wave(deg)	−10.064	−13.406	−16.207	−18.569	−22.225	−24.607
(rad)	−0.1756	−0.2340	−0.2828	−0.3241	−0.3879	−0.4294
d wave(deg)	3.622	5.005	6.728	7.818	10.296	11.779
(rad)	0.0632	0.0873	0.1174	0.1364	0.1797	0.2056
f wave(deg)	0.759	—	1.352	1.275	1.971	2.333
(rad)	0.0132	—	0.0236	0.0223	0.0344	0.0407
Scaling factor λ	1.06	1.01	0.98	0.93	1.01	1.00
Number of phases fitted	5	3	4	6	4	5
$P_{\min}$	0.127	0.379	1.199	0.723	0.204	0.234
$\sigma_t(E)$ (a_0^2)	11.6 ± 0.6	12.4 ± 0.6	12.4 ± 0.6	12.2 ± 0.6	13.6 ± 0.7	13.6 ± 0.7
$\sigma_m(E)$ (a_0^2)	8.1 ± 0.5	8.7 ± 0.5	8.9 ± 0.5	8.9 ± 0.5	10.4 ± 0.6	10.6 ± 0.6

The derived s-, p- and d-wave phaseshifts are plotted in figure 2 with the data of other workers for comparison. With the exception of the data of Naccache and McDowell (1974) the general agreement between the various authors is clearly evident. Naccache and McDowell derived their data largely from a phaseshift analysis of McConkey and Preston's data and, although for the s wave at $E < 7$ eV they are indistinguishable from Williams' data, their remaining s-wave data show a totally different energy dependence. Nevertheless Thompson's (1971) theoretical data show a preference for Naccache and McDowell's p-wave data while showing general agreement with Andrick's experimentally derived s- and p-wave data. The theoretical

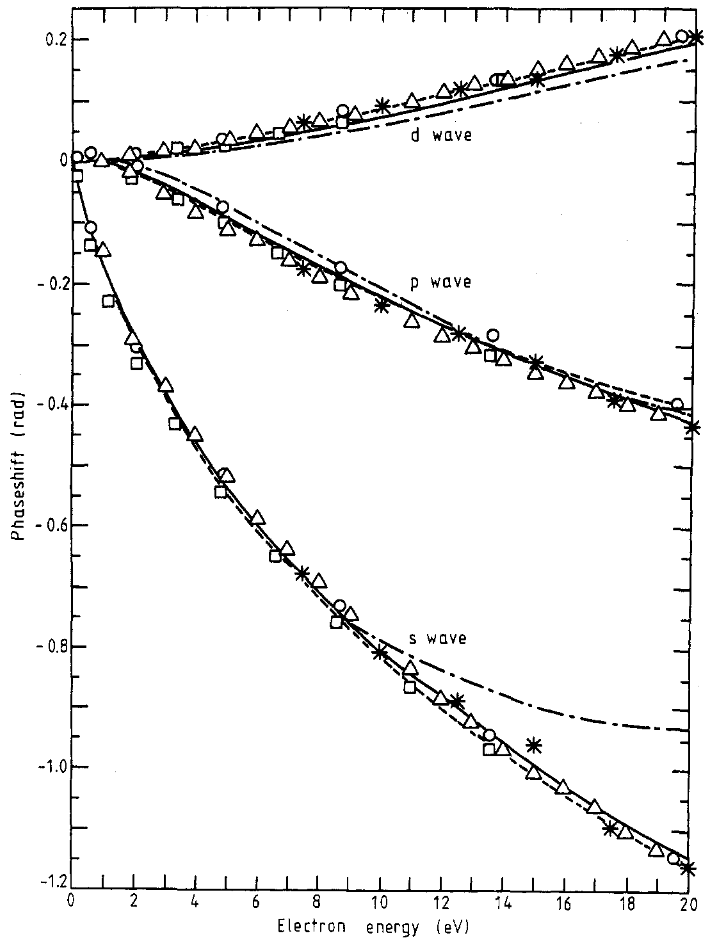

Figure 2. Elastic scattering of electrons from neon atoms: s, p and d phaseshifts. *, present measurements; △, Andrick (1978); ○, Thompson (1971); □, Garbarty and LaBahn (1971); ———, Williams (1979); - - - -, Yau *et al* (1978); — · —, Naccache and McDowell (1974).

results of Yau *et al* (1978) also show overall agreement with Andrick's data, again with the exception of the p wave. The present work shows the best agreement with the data of Andrick with the exception of the 15 eV point which is slightly displaced from the trend of the s phaseshift.

The derived total and momentum transfer cross sections are also listed in table 2. If the 15 eV data is in error (due to the poor s-wave fit) then the present results favour the total cross section data of Ramsauer (1921a, b), whilst they are on average about 2% lower than the measurements of Stein *et al* (1978) and about 2% higher than the measurements of Salop and Nakano (1970). There is good agreement with the derived results of Andrick, as expected, due to the good agreement in the phaseshifts.

The calculations of Thompson (1966, 1971) account for both exchange and polarisation effects using the method of Temkin (1957) to estimate the polarisation potential. The earlier results reproduce the shape of Salop and Nakano's experimental curve quite well, but give cross sections 4–12% higher over its range of energy. They are, however, in good agreement with the recent measurements of Stein *et al*. The later calculations of Thompson are in excellent agreement with the measurements of Salop and Nakano, and as such are an average of about 2% lower than the present results.

The present work provides the first complete set of absolute differential cross sections for elastic scattering of electrons from neon for energies in the range 7.5 to 20 eV available in the literature.

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