forms of the C's are

$$C_1^{KE} = d^2 \sum_{\nu=0}^{2} \left\{ (-1)^\nu \binom{2}{\nu} \frac{\nu}{2} \frac{(\nu\, d)^2 + 2\, k^2}{\nu\, d\,[(\nu\, d)^2 + 4\, k^2]} \right\} + 2\, k^2\, d \sum_{\nu=0}^{2} \left\{ (-1)^\nu \binom{2}{\nu} \frac{\nu}{2} \frac{1}{(\nu\, d)^2 + 4\, k^2} \right\},$$

$$C_2^{KE} = \sum_{\nu=0}^{2} (-1)^\nu \binom{2}{\nu} \left\{ \left(c^2 + \frac{\nu}{2} (2\, c\, d + d^2) \right) \cdot \frac{(2\, c + \nu\, d)^2 + 2\, k^2}{(2\, c + \nu\, d)\,[(2\, c + \nu\, d)^2 + 4\, k^2]} + \frac{k^2 (2\, c + \nu\, d)}{(2\, c + \nu\, d)^2 + 4\, k^2} \right\},$$

$$C_3^{KE} = \sum_{\nu=0}^{2} (-1)^\nu \binom{2}{\nu} \left\{ [c^2 + \nu (c\, d + d^2)] \cdot \frac{(c + \nu\, d)^2 + 2\, k^2}{(c + \nu\, d)\,[(c + \nu\, d)^2 + 4\, k^2]} + \frac{2\, k^2 (c + \nu\, d)}{(c + \nu\, d)^2 + 4\, k^2} \right\},$$

$$C_4^{KE} = -k\,, \qquad C_5^{KE} = 0\,,$$

$$C_1^{PE} = Z \sum_{n} \sum_{\nu=0}^{2} (-1)^{\nu+1} \binom{2}{\nu} 2^{-1} A_n \cdot [\ln((\gamma_n + \nu\, d)^2 + 4\, k^2) + 2 \ln(\gamma_n + \nu\, d)],$$

$$C_2^{PE} = Z \sum_{n} \sum_{\nu=0}^{2} (-1)^{\nu+1} \binom{2}{\nu} 2^{-1} A_n \cdot [\ln((\gamma_n + 2\, c + \nu\, d)^2 + 4\, k^2) + 2 \ln(\gamma_n + 2\, c + \nu\, d)],$$

$$C_3^{PE} = 2\, Z \sum_{n} \sum_{\nu=0}^{2} (-1)^{\nu+1} \binom{2}{\nu} 2^{-1} A_n \cdot [\ln((\gamma_n + c + \nu\, d)^2 + 4\, k^2) + 2 \ln(\gamma_n + 2\, c + \nu\, d)],$$

$$C_4^{PE} = Z \sum_{n} A_n \arctan \frac{2\, k\, d}{\gamma_n (\gamma_n + d) + 4\, k^2},$$

$$C_5^{PE} = Z \sum_{n} A_n \arctan \frac{2\, k\, d}{(\gamma_n + c)\,(\gamma_n + c + d) + 4\, k^2},$$

$$C_0^{PE} = -Z \sum_{n} 2^{-1} A_n \ln \frac{\gamma_n^2}{\gamma_n^2 + 4\, k^2},$$

The equation (19 a) gives [15]

$$a\, k = (C_4^{KE} + C_4^{PE})\, a + (C_5^{KE} + C_5^{PE})\, b + 2\, C_0\,.$$

Elastic Scattering of Low Energy Positrons by Atoms

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Elastic scattering cross sections of low energy positrons (0 to about 40 eV) by Helium, Carbon, Nitrogen, Oxygen, Fluorine, Neon and Argon atoms are calculated by variational methods. The scattering potentials are taken to be the analytical approximations of different Hartree potentials. Only s-wave is included. Comparisons with the available experimental datas of positron scattering by He, Ne and A reveal that either a considerable strong polarisation potential will be required to bring the theoretical results at par with experiments or the formation of virtual positronium play a dominant role for this kind of elastic scattering.

Lately some experimental results are available for the elastic scattering of positrons by atoms and this has revived naturally some interest to treat this problem theoretically. This problem is theoretically simpler than electron scattering since there is no exchange between the scattered positrons and the bound electrons. Massey and Moussa [1] treated theoretically the positron scattering by He, Ne, A and H atoms in Hartree-approximation where the total wave functions of the system is written as a product of atomic wave function and the scattered wave function; they solved the derived differential equation for the scattered wave function numerically using Hartree wave functions for the atomic electrons of Ne and Hartree–Fock wave functions for He and H. Their results indicate that for positron scattering the polarisation is of fundamental importance [2]. On the other hand it seems that the comparison of the experimental datas with the theoretical calculations of no-polarisation approximation may serve as a possible mean to determine the polarisation effect so long as one tends to take this effect in a potential form. The already theoretically available calculations of polarisation potential by perturbation methods have more validity for positron scattering since in most of the cases, the ex-

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[1] H. S. W. Massey and A. H. A. Moussa, Proc. Phys. Soc., Lond. **71**, 38 [1958].

[2] cp. also A. H. A. Moussa, Proc. Phys. Soc., Lond. **74**, 101 [1959].

change between the scattered particle and the bound electrons is neglected in doing perturbation calculation. If such a polarisation potential may be found, which together with the atomic potential reproduces the elastic scattering experimental datas, this same polarisation potential should also be useful for electron scattering.

This view in mind we have carried out the calculation for positrons, scattered by He, C, N, O, F, Ne and A, in HARTREE approximation and for s-wave using variational methods.

The scattering equation

If the total wave function of the system is written as a product of the atomic wave function Φ and the scattered positron wave function F, the equation for the scattered positron is given by

$$[\Delta + k^2 - 2\,V(r)]\,F(r) = 0 \qquad (1)$$

(k: wave number), where

$$V(r) = -\frac{Z}{r} + \sum_{n=1}^{N} \int \mathrm{d}\mathfrak{r}_1 \int \mathrm{d}\mathfrak{r}_2 \ldots \cdot \int \mathrm{d}\mathfrak{r}_N \frac{|\Phi(\mathfrak{r}_1 \ldots \mathfrak{r}_N)|^2}{|\mathfrak{r}_{N+1} - \mathfrak{r}_i|}. \qquad (2)$$

Here Z is atomic number, $\mathfrak{r}_1 \ldots \mathfrak{r}_N$ are the position vectors of N bound electrons and $\mathfrak{r}_{N+1}$ that of the positron.

For $V(r)$ one may use the charge density as given by HARTREE or HARTREE–FOCK wave functions for bound electrons. This can be very well approximated by a series of exponential functions as done by HOLTSMARK [3], RUARK [4], and BYATT [5]. For $N = Z$ i. e. neutral atom

$$V(r) = -\frac{Z}{r} \sum_n A_n \exp(-\gamma_n r)\,, \qquad (3)$$

A_n and γ_n are parameteres depending on the atomic number Z. We expand

$$F(\mathfrak{r}) = \sum_{l,m} a_{l,m} \frac{\chi_l(r)}{r}\, y_{l,m}(\Theta, \varphi)$$

where $y_{l,m}(\Theta, \varphi)$ is a normalised spherical harmonic. Multiplying (1) with $y^*_{l,m}(\Theta, \varphi)$ and then integrating over the angles we get

$$\left[\frac{\mathrm{d}^2}{\mathrm{d}r^2} + k^2 - \frac{l(l+1)}{r^2} - 2\,V(r)\right]\chi_l(r) = 0\,. \qquad (4)$$

[3] J. HOLTSMARK, Z. Phys. **66**, 49 [1930].
[4] A. E. RUARK, Phys. Rev. **57**, 62 [1940].

The total scattering cross section is given by

$$Q = \frac{4\pi}{k^2} \sum_{l=0}^{\infty} (2l+1) \sin^2 \lambda_l$$

where λ_l is defined by the regular solution of (4), which has the asymptotic form

$$\chi_l(r) \underset{r\to\infty}{\to} \text{const} \sin\left(k\,r - \frac{\pi\,l}{2} + \lambda_l\right).$$

In this work, we are concerned only with the case $l = 0$ and henceforth the index l will be dropped.

The equation (4) is solved by the usual variational methods [6] namely by varying L where

$$L = \int \chi(r) \left[\frac{\mathrm{d}^2}{\mathrm{d}r^2} + k^2 - 2\,V(r)\right]\chi(r)\,\mathrm{d}r\,.$$

The trial wave function is taken to be of the form

$$\chi(r) = \sin k\,r + (a + b\,e^{-c\,r})\,(1 - e^{-d\,r})\cos k\,r \qquad (5)$$

where a, b, c, and d are variational parameters. In actual calculation, a and b are determined by variation:

$$\partial L/\partial b = 0$$

and one of the three equations [6]

$$L = 0 \qquad \text{(HULTHÉN's method)}$$

$$\partial L/\partial a = -k \quad \text{together with } \mathrm{tg}\,\lambda = a + (L/k) \text{ (KOHN's method)},$$

$$a = k^{-1} \int_0^{\infty} \sin k\,r \cdot 2\,V\,\chi\,\mathrm{d}r \quad \text{together with } \mathrm{tg}\,\lambda = a + (L/k) \ (3^{\mathrm{rd}} \text{ method}),$$

c and d are assumed to be equal, and are determined in such a way that all three variational methods give almost the same result (it can be shown [6] that if two of the methods give the same result, also the third one does).

Results and Discussion

We have calculated the positron scattering by Helium, Carbon, Oxygen, Nitrogen, Fluorine, Neon, Argon. In general it was found that the phase shift is not very sensitive to the choice of c and d in contrast to the case of electron scattering [6]. Our variational methods give for the cases of Helium, Neon and Argon almost the same results as those of MASSEY and MOUSSA [1] who solved the differential equation (4) numerically using also the numerically

[5] W. O. BYATT, Phys. Rev. **104**, 1298 [1956].
[6] F. B. MALIK and E. TREFFTZ, Z. Naturforschg. **16 a**, 492 [1961].

	Z	c	k^2	k	λ_K	λ_H	λ_t	Q_K°	Q_H°	Q_t°
He	2	1,6875	3.694	1.922	— 0.510	— 0.519	— 0.518	0.258	0.266	0.265
			1.847	1.359	— 0.437	— 0.438	— 0.438	0.388	0.389	0.389
			1.323	1.150	— 0.394	— 0.394	— 0.394	0.446	0.446	0.446
			1.109	1.053	— 0.371	— 0.371	— 0.371	0.475	0.475	0.475
			1.000	1.000	— 0.358	— 0.358	— 0.358	0.491	0.491	0.491
			0.074	0.272	— 0.113	— 0.113	— 0.113	0.687	0.687	0.687
			0.018	0.136	— 0.057	— 0.057	— 0.057	0.707	0.707	0.707
C	6	1.0	1.50	1.225	— 1.015	— 1.164	— 1.074	1.923	2.250	2.061
			1.00	1.000	— 0.941	— 0.989	— 0.965	2.612	2.791	2.702
			0.80	0.894	— 0.887	— 0.909	— 0.898	3.005	3.113	3.060
			0.50	0.707	— 0.755	— 0.757	— 0.756	3.759	3.774	3.766
			0.10	0.316	— 0.372	— 0.373	— 0.372	5.277	5.319	5.277
			0.05	0.224	— 0.267	— 0.268	— 0.267	5.561	5.617	5.580
N	7	1,4	2.00	1.414	— 1.013	— 1.177	— 1.070	1.440	1.705	1.540
			1.50	1.225	— 0.961	— 1.060	— 0.993	1.793	2.030	1.871
			1.00	1.000	— 0.862	— 0.891	— 0.873	2.307	2.421	2.348
			0.80	0.894	— 0.800	— 0.814	— 0.805	2.574	2.644	2.599
			0.50	0.707	— 0.667	— 0.670	— 0.668	3.064	3.082	3.070
			0.10	0.316	— 0.322	— 0.322	— 0,322	3.998	4.002	3.999
			0.05	0.224	— 0.230	— 0.230	— 0.230	4.160	4.160	4.160
O	8	1.45	1.50	1.225	— 0.957	— 0.997	— 0.971	1.782	1.881	1.817
			1.00	1.000	— 0.834	— 0.841	— 0.837	2.194	2.222	2.206
			0.80	0.894	— 0.764	— 0.766	— 0.765	2.393	2.403	2.398
			0.50	0.707	— 0.626	— 0.626	— 0.626	2.746	2.746	2.746
			0.25	0.500	— 0.457	— 0.458	— 0.457	3.115	3.128	3.115
			0.10	0.316	— 0.296	— 0.297	— 0.296	3.404	3.426	3.404
			0.05	0.224	— 0.211	— 0.212	— 0.211	3.509	3.542	3.509
F	9	1.4	1.50	1.225	— 0.943	— 0.990	— 0.962	1.747	1.864	1.795
			1.00	1.000	— 0.830	— 0.841	— 0.834	2.178	2.222	2.194
			0.80	0.894	— 0.764	— 0.768	— 0.765	2.393	2.413	2.398
			0.50	0.707	— 0.630	— 0.630	— 0.630	2.777	2.777	2.777
			0.25	0.500	— 0.462	— 0.462	— 0.462	3.179	3.179	3.179
			0.10	0.316	— 0.299	— 0.300	— 0.300	3.471	3.493	3.493
			0.05	0.224	— 0.214	— 0.214	— 0.214	3.608	3.608	3.608
Ne	10	1.6	1.50	1.225	— 0.882	— 0.905	— 0.891	1.589	1.649	1.613
			1.00	1.000	— 0.763	— 0.767	— 0.765	1.910	1.926	1.918
			0.80	0.894	— 0.698	— 0.699	— 0.698	2.065	2.070	2.065
			0.50	0.707	— 0.571	— 0.571	— 0.571	2.337	2.337	2.337
			0.25	0.500	— 0.416	— 0.416	— 0.416	2.613	2.613	2.613
			0.10	0.316	— 0.268	— 0.269	— 0.269	2.804	2.825	2.825
			0.05	0.224	— 0.191	— 0.192	— 0.191	2.883	2.913	2.883
A	18	0.65	1.324	1.150	— 1.169	— 1.313	— 1.239	2.560	2.826	2.701
			1.000	1.000	— 1.116	— 1.206	— 1.157	3.227	3.490	3.354
			0.800	0.894	— 1.062	— 1.103	— 1.084	3.813	3.982	3.905
			0.500	0.707	— 0.917	— 0.918	— 0.918	5.038	5.050	5.045
			0.250	0.500	— 0.683	— 0.688	— 0.686	6.369	6.459	6.422
			0.100	0.316	— 0.448	— 0.456	— 0.452	7.507	7.754	7.629
			0.050	0.224	— 0.323	— 0.328	— 0.325	8.053	8.322	8.173

Table 1. The phase shifts and the cross section of positron scattering by Helium, Carbon, Nitrogen, Oxygen, Fluorine, Neon, and Argon. K, H, and t refer to the variational methods of KOHN, HULTHÉN and allied one respectively.

available values for $V(r)$. This agreement makes it plausible that the results obtained for other cases are reliable.

In Table 1, the phase shifts for the three different variational methods (suffices K, H and t refer to the methods of KOHN, HULTHÉN and the third one respectively), and the corresponding cross sections are given for various energies (in atomic unit) for the scattering by Helium, Carbon, Nitrogen, Oxygen, Fluorine, Neon, and Argon.

	Z	c	k^2	a_K	a_H	a_t	b_K	b_H	b_t	$L_{K/k}$	Integration for tg λ_H	$L_{t/k}$
He	2	1.688	3.694	− 0.276	− 0.571	− 0.548	− 0.521	− 0.122	− 0.153	− 0.283	− 0.547	− 0.021
			1.847	− 0.397	− 0.468	− 0.461	− 0.185	− 0.085	− 0.095	− 0.070	− 0.460	− 0.007
			1.323	− 0.394	− 0.416	− 0.414	− 0.102	− 0.071	− 0.075	− 0.022	− 0.413	− 0.003
			1.109	− 0.382	− 0.389	− 0.388	− 0.075	− 0.065	− 0.066	− 0.007	− 0.388	− 0.001
			1.000	− 0.372	− 0.374	− 0.374	− 0.064	− 0.062	− 0.062	− 0.001	− 0.374	− 0.000
			0.074	− 0.120	− 0.113	− 0.115	− 0.009	− 0.017	− 0.015	0.006	− 0.115	0.001
			0.018	− 0.060	− 0.057	− 0.058	− 0.005	− 0.009	− 0.008	0.003	− 0.058	0.001
C	6	1.0	1.50	− 0.424	− 2.323	− 1.517	− 1.098	− 1.539	0.419	− 1.185	− 1.449	− 0.328
			1.00	− 0.732	− 1.520	− 1.277	− 0.440	0.683	0.336	− 0.640	− 1.234	− 0.166
			0.80	− 0.833	− 1.284	− 1.153	− 0.166	0.487	0.296	− 0.394	− 1.122	− 0.103
			0.50	− 0.854	− 0.945	− 0.918	0.127	0.261	0.221	− 0.088	− 0.908	− 0.025
			0.10	− 0.423	− 0.392	− 0.404	0.103	0.055	0.074	0.033	− 0.414	0.014
			0.05	− 0.298	− 0.275	− 0.284	0.069	0.034	0.049	0.024	− 0.292	0.011
N	7	1.4	2.00	− 0.556	− 2.404	− 1.467	− 0.697	1.970	0.618	− 1.048	− 1.326	− 0.361
			1.50	− 0.737	− 1.786	− 1.299	0.280	1.259	0.545	− 0.695	− 1.183	− 0.235
			1.00	− 0.842	− 1.238	− 1.077	0.092	0.686	0.445	− 0.325	− 1.016	− 0.115
			0.80	− 0.831	− 1.059	− 0.967	0.188	0.534	0.394	− 0.199	− 0.923	− 0.074
			0.50	− 0.726	− 0.792	− 0.764	0.243	0.343	0.300	− 0.062	− 0.746	− 0.025
			0.10	− 0.341	− 0.333	− 0.337	0.125	0.114	0.120	0.007	− 0.341	0.004
			0.05	− 0.241	− 0.234	− 0.238	0.088	0.078	0.083	0.007	− 0.241	0.003
O	8	1.45	1.50	− 0.951	− 1.546	− 1.299	− 0.008	0.835	0.498	− 0.468	− 1.183	− 0.163
			1.00	− 0.943	− 1.119	− 1.049	0.224	0.351	0.382	− 0.160	− 0.818	− 0.059
			0.80	− 0.886	− 0.963	− 0.932	0.260	1.062	0.329	− 0.073	− 1.961	− 0.028
			0.50	− 0.729	− 0.723	− 0.726	0.245	0.003	0.240	− 0.006	− 0.352	0.002
			0.25	− 0.518	− 0.493	− 0.505	0.175	0.614	0.154	0.026	− 1.321	0.012
			0.10	− 0.325	− 0.306	− 0.315	0.105	0.392	0.091	0.021	− 0.874	0.010
			0.05	− 0.229	− 0.215	− 0.222	0.073	0.178	0.062	0.015	− 0.452	0.008
F	9	1.40	1.50	− 0.849	− 1.522	− 1.265	− 0.156	1.391	0.449	− 0.529	− 1.803	− 0.168
			1.00	− 0.893	− 1.117	− 1.036	0.143	0.012	0.354	− 0.201	− 0.461	− 0.068
			0.80	− 0.856	− 0.965	− 0.925	0.205	1.074	0.308	− 0.103	− 1.763	− 0.036
			0.50	− 0.721	− 0.729	− 0.726	0.222	0.713	0.229	− 0.008	− 1.344	− 0.003
			0.25	− 0.519	− 0.498	− 0.507	0.166	0.045	0.149	0.021	− 0.393	0.009
			0.10	− 0.327	− 0.310	− 0.318	0.101	0.337	0.087	0.018	− 0.697	0.009
			0.05	− 0.231	− 0.218	− 0.224	0.070	0.006	0.060	0.014	− 0.167	0.007
Ne	10	1.60	1.50	− 0.892	− 1.272	− 1.128	0.063	0.228	0.412	− 0.322	− 0.629	− 0.108
			1.00	− 0.848	− 0.964	− 0.920	0.215	0.129	0.323	− 0.108	− 0.580	− 0.040
			0.80	− 0.788	− 0.841	− 0.820	0.233	0.957	0.281	− 0.050	− 1.617	− 0.019
			0.50	− 0.645	− 0.642	− 0.643	0.212	0.771	0.210	0.003	− 1.387	0.001
			0.25	− 0.460	− 0.442	− 0.450	0.153	0.101	0.138	0.018	− 0.424	0.008
			0.10	− 0.290	− 0.276	− 0.283	0.094	0.353	0.083	0.015	− 0.687	0.007
			0.05	− 0.204	− 0.194	− 0.199	0.065	0.250	0.057	0.011	− 0.492	0.006
A	18	0.65	1.324	− 0.318	− 3.791	− 2.265	− 1.998	2.441	0.491	− 2.037	− 2.195	− 0.635
			1.000	− 0.668	− 2.616	− 1.917	− 1.313	1.208	0.303	− 1.375	− 1.846	− 0.362
			0.800	− 0.907	− 1.977	− 1.679	− 0.811	0.592	0.202	− 0.885	− 1.636	− 0.209
			0.500	− 1.162	− 1.309	− 1.276	− 0.081	0.116	0.072	− 0.142	− 1.268	− 0.031
			0.250	− 0.976	− 0.823	− 0.860	0.150	− 0.064	− 0.013	0.163	− 0.874	0.041
			0.100	− 0.592	− 0.490	− 0.521	0.058	− 0.085	− 0.042	0.111	− 0.537	0.035
			0.050	− 0.403	− 0.341	− 0.361	0.019	− 0.069	− 0.040	0.069	− 0.374	0.024

Table 2. The values of the parameters and the reliability conditions for s-wave positron scattering by Helium, Carbon, Nitrogen, Oxygene, Fluorine, Neon, and Argon.

Table 2 list the values of the different parameters for the scattering by He, C, and N; O, F, and Ne and A respectively. The values of the so-called reliability conditions are also given; a_H is to be of the same order as the "integration for tg λ_H", L_K/k and L_t/k are to be small in comparison with a_K and a_t respectively.

Figs. 1, 2 and 3 give the phase shifts obtained by

the three different variational methods, as functions of energy for the cases Helium, Carbon and Oxygen (Fig. 1), Nitrogen and Neon (Fig. 2), and Fluorine

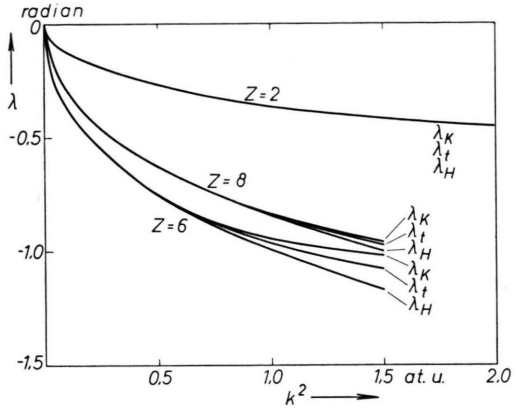

Fig. 1. Phase shift of elastically scattered s-electron by He, O, and C.

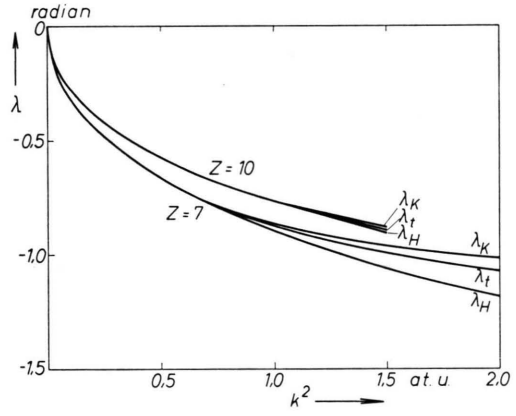

Fig. 2. Phase shift of elastically scattered s-electrons by Ne and N.

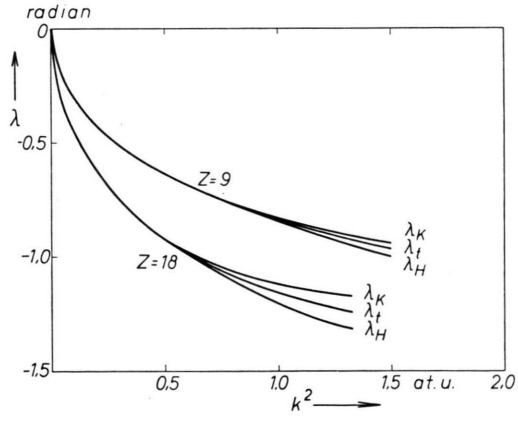

Fig. 3. Phase shift of elastically scattered s-electrons by F and A.

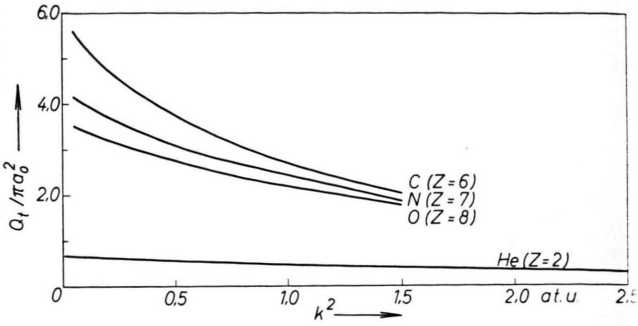

Fig. 4. Elastic scattering cross sections for He, C, N, and O (s-scattering only).

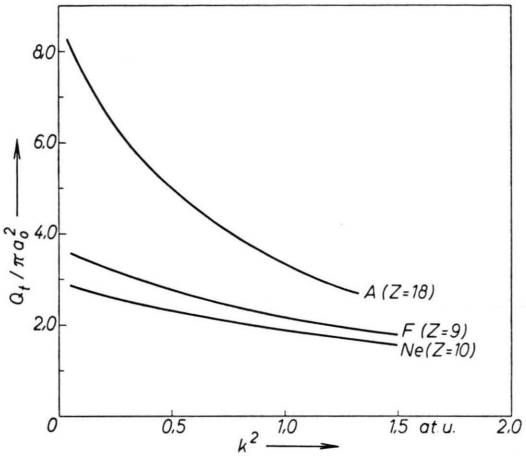

Fig. 5. Elastic scattering cross sections for F, Ne and A (s-scattering only).

and Argon (Fig. 3). Figs. 4 and 5 refer to the total cross section for the scattering by He, C, N, and O and F, N and A respectively.

The cross sections obtained from the experiments by MARDER, HUGHES, WU and BENNETT [7] are 0.023, 0.12 and $1.5\,\pi a_0^2$ for Helium, Neon and Argon respectively for a mean positron energy of 18 eV, i. e. $k^2 = 1.323$; these are to be compared with our results of 0.45, about 1.7 and $2.6\,\pi a_0^2$ respectively. Since the inclusions of higher waves will only enlarge the theoretical result, it seems that the polarisation effect is of considerable magnitude in comparison with the central atomic potential. For Argon one can expect a considerable contribution to the total cross section by higher angular momenta. Therefore the effect of polarisation is difficult to

[7] S. MARDER, V. W. HUGHES, C. S. WU and W. BENNETT, Phys. Rev. **103**, 1258 [1956].

estimate. The general behaviour of the phase shift is the same for all cases: All phase shifts are negative as expected from a repelling potential. For increasing energy they decrease steeply and then rather gradually showing no minimum.

All calculations are performed on the G 2 electronic computer.

I thank Dr. TREFFTZ for many valuable discussions and Professor HEISENBERG and BIERMANN for their interest. The work of the calculating group here in tabulating the results and drawing is very much appreciated.

Messung extrem kurzer Zerfallszeiten organischer Ionen mit dem Feldionisations-Massenspektrometer

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Mit Hilfe einer Feldemissions-Ionenquelle in Verbindung mit einem Massenspektrometer kann man sehr kurze Zerfallszeiten organischer Ionen bis zu Minimalwerten von einigen 10^{-14} sec messen. Beispiele für derart kurze Zerfallszeiten wurden bisher nur bei organischen Ionen gefunden; jedoch ist die Methode nicht auf organische Stoffe beschränkt, sondern kann zur Messung aller zwischen einigen 10^{-14} und 10^{-7} sec liegenden Ionen-Zerfallszeiten benutzt werden. Damit ist der Bereich der massenspektroskopischen Meßbarkeit der Lebensdauer von Ionen um mehrere Zehnerpotenzen gegenüber der Elektronenstoßmethode erweitert.

Die Beziehungen zwischen den Zerfallszeiten der Ionen und der Verbreiterung der Linien im Massenspektrum werden theoretisch abgeleitet. Vorläufige Versuche über die Dissoziation des Butans und Neopentans bestätigen die Anwendbarkeit der Feldionisationsmethode zur Messung extrem kurzer Zerfallszeiten; es wurden Lebensdauern der Mutterionen von etwa $5 \cdot 10^{-14}$ sec gefunden.

Die Zerfallszeiten angeregter organischer Ionen können grundsätzlich mit Hilfe des Massenspektrometers gemessen werden. Bei Verwendung einer Elektronenstoß-Ionenquelle üblicher Bauart liegt der Bereich der meßbaren Zerfallszeiten zwischen etwa 10^{-5} und 10^{-6} sec.

Mit Hilfe einer Feldemissions-Ionenquelle kann man den Meßbereich bis zu kürzesten Zerfallszeiten im Bereich einiger 10^{-14} sec erweitern. Der Grund liegt darin, daß der Enstehungsort der Mutterionen in diesem Falle äußerst scharf lokalisiert ist (im allgemeinen bis auf einige Å) und daß dort der elektrische Potentialgradient so groß ist (etwa 10^8 V pro cm), daß die Ionen, die einige Å von der Ionenerzeugenden Spitze entfernt zerfallen, sich im elektrischen Potential um einige Volt von dem Spitzenpotential unterscheiden. Der Potentialunterschied der Fragmentionen gegenüber den näher an der Spitze gebildeten Mutterionen läßt sich bei einer Gesamtspannung zur Ionenerzeugung von einigen kV gut als Verschiebung bzw. Verbreiterung der Linien im Massenspektrum nachweisen. Da einer Flugstrecke von einigen Å eine Laufzeit von einigen 10^{-14} sec entspricht, ist dies die untere Grenze für die Messung der Laufzeit der Mutterionen von ihrer Bildung bis zum Zerfall.

Im folgenden sollen die theoretischen Beziehungen zwischen den Zerfallszeiten organischer Ionen und der Verbreiterung der Linien des Massenspektrums theoretisch abgeleitet und vorläufige experimentelle Ergebnisse über den Zerfall des Butans und Neopentans mitgeteilt werden.

Berechnung der Laufzeit der Mutterionen als Funktion von r/r_0 bzw. U/U_0

Für die nachfolgenden Rechnungen genügt es vorerst, das Potential vor einer Spitze mit dem Krümmungsradius r_0 durch die Potentialverteilung zwischen einer Kugel mit dem Radius r_0 und einer konzentrischen kugelförmigen Gegenelektrode mit dem Radius R anzunähern. Das Potential zwischen Spitze und Gegenelektrode im Abstand r vom Krümmungsmittelpunkt der Spitze hat folgenden Verlauf:

$$U = U_0 \left[\frac{r_0/r - r_0/R}{1 - r_0/R} \right], \qquad (1)$$

wobei U_0 das positive Potential der Spitze gegenüber dem auf Null befindlichen Potential der Gegenelektrode bedeutet.