

## Check of Electron Backscattering Coefficients at 10 and 20 MeV

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Backscattering coefficients for  $Z=13, 29, 48, 82$  were re-determined with a large area proportional counter containing an insensitive tube passed by the incident beam. Results confirm our previous experience and semiempirical formula. Dressel has recently identified errors in his deviating values.

Values of the total backscattering coefficient in the region 1 MeV to 22 MeV, reported previously<sup>3</sup> according to measurements of FRANK<sup>1</sup>, WRIGHT and TRUMP<sup>2</sup>, and HARDER and FERBERT<sup>3</sup>, have since been confirmed by GLAZUNOV and GUGLYA<sup>4</sup>, COHEN and KORAL<sup>5</sup>, RESTER and RAINWATER<sup>6</sup> and TABATA<sup>7</sup>. Previous data of MILLER<sup>8</sup> and SALLICK and ALLEN<sup>9</sup> also show good agreement. However, values surmounting the former by a factor of the order of 1.5 to 2.5 have been obtained by DRESSEL<sup>10</sup>. Possible experimental reasons for this deviation were discussed by DRESSEL and TABATA, but quantitative understanding was not yet achieved. In view of this discrepancy the present experiment was planned to check our previous results<sup>3</sup> by an independent method.

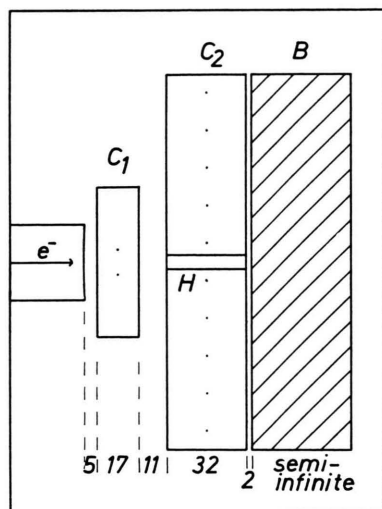


Fig. 1. Setup for backscattering experiment.  $C_1$ ,  $C_2$  counters, B backscatterer, H Hostaphan-tube. Measures in mm.

The collimated electron beam of the Würzburg 35 MeV betatron was focused to 1 mm diameter and  $2 \cdot 10^{-4}$  radians divergency by a magnetic beam guide containing two sector magnets and a quadrupole pair<sup>11</sup>. The relative width of the electron energy spectrum was  $10^{-3}$ . After passing the beam guide exit window (Hostaphan 2 mg/cm<sup>2</sup>) and two methane-filled thin window counters<sup>12</sup> (total thickness 10 mg/cm<sup>2</sup>), separated by some millimeters of air, the beam perpendicularly entered the plane-faced semi-infinite backscatterer (Fig. 1). The counting efficiency of the first counter, containing two wires and acting in the Geiger mode, was 100%. The second counter, containing 10 wires and working in the proportional region, was equipped with a 5.5 mm diameter, 0.1 mm Hostaphan-walled field-free tube in line with the electron beam. The counting efficiency of this counter, established by scanning with the 1 mm wide electron beam, was zero for electrons travelling along this tube, but 100% for electrons entering the remainder of the counter. With the setup of Fig. 1 the second counter, therefore, was not triggered by the incident electron beam except by some few electrons scattered beside the field-free tube, whereas the back-scattered electrons triggered this counter upon entering the sensitive main part of it.

The backscattering coefficient  $p$  was obtained from the count rates  $n$  by the relation

$$p = n_{2b}/n_{1b} - n_{20}/n_{10}, \quad (1)$$

where subscripts 1 and 2 denote the first and second counter and subscripts b and 0 denote the measurement with respectively without backscatterer. Background counts were suppressed by gating the counters in phase with the betatron pulses. By appropriate checks it was shown that the contribution to  $n_{20}$  by backscattering from the air volume backing the second counter was negligible, as well as the loss from  $n_{2b}$  by backscattered electrons travelling through the field-free tube or escaping from the gap between backscatterer B and counter  $C_2$ . Secondary electrons from the backscatterer with energies below 25 keV were shielded from counter 2 by the back entrance foil; secondaries of higher energy contributed to the count rate unless they arrived in coincidence with backscattered primaries. The contribution of such coincident secondary electrons to the total spectrum of electrons directed backward may be estimated from measurements in the forward hemisphere<sup>13</sup> to be 5 to 10% of the number of primary electrons scattered back. This effect was allowed for by a correction factor  $1.075 \pm 0.025$ .

<sup>1</sup> H. FRANK, Z. Naturforsch. **14 a**, 247 [1959].

<sup>2</sup> K. A. WRIGHT and J. G. TRUMP, J. Appl. Phys. **33**, 687 [1962].

<sup>3</sup> D. HARDER and H. FERBERT, Phys. Letters **9**, 233 [1964].

<sup>4</sup> P. YA. GLAZUNOV and V. G. GUGLYA, Dokl. Akad. Nauk SSSR **159**, 632 [1964] (cited after TABATA).

<sup>5</sup> A. J. COHEN and K. F. KORAL, NASA TND-2782 (unpublished, cited after TABATA).

<sup>6</sup> D. H. RESTER and W. J. RAINWATER, JR., Nucl. Inst. Meth. **41**, 51 [1966].

<sup>7</sup> T. TABATA, Phys. Rev. **162**, 336 [1967].

<sup>8</sup> B. L. MILLER, Rev. Sci. Instrum. **23**, 401 [1952].

<sup>9</sup> J. SALLICK and A. O. ALLEN, J. Chem. Phys. **22**, 438, 1777 [1954].

<sup>10</sup> R. W. DRESSEL, Phys. Rev. **144**, 332 [1966].

<sup>11</sup> M. SCHEER, in: 4th Internat. Betatron Symposium, Prague 1966.

<sup>12</sup> D. HARDER, in: 4th Internat. Betatron Symposium, Prague 1966.

<sup>13</sup> D. HARDER and H. J. SCHULZ, in: Proc. Symp. on Microdosimetry, European Atomic Energy Community, Brussels 1968.



$E_0$	8.4 MeV	10.0 MeV	11.9 MeV	15.0 MeV	19.8 MeV	20.0 MeV	22.2 MeV
Pb	$16.0 \pm 0.3$	$13.4 \pm 0.4$	$10.7 \pm 0.3$	$8.1 \pm 0.3$	$5.3 \pm 0.2$	$5.7 \pm 0.3$	$4.5 \pm 0.2$
Cd	$9.5 \pm 0.3$	$7.2 \pm 0.4$	$5.9 \pm 0.2$	$4.4 \pm 0.2$	$2.8 \pm 0.2$	$2.5 \pm 0.2$	$2.5 \pm 0.2$
Cu	$4.1 \pm 0.2$	$4.0 \pm 0.5$	$2.8 \pm 0.2$	$2.0 \pm 0.1$	$1.6 \pm 0.1$		$1.4 \pm 0.1$
Al	$1.2 \pm 0.1$		$0.9 \pm 0.1$	$0.8 \pm 0.1$	$0.5 \pm 0.1$		$0.5 \pm 0.1$

Tab. 1. Backscattering coefficients, experimental results, in %.  
(10 and 20 MeV: Present experiment. Other energies: HARDER and FERBERT, corrected values.)

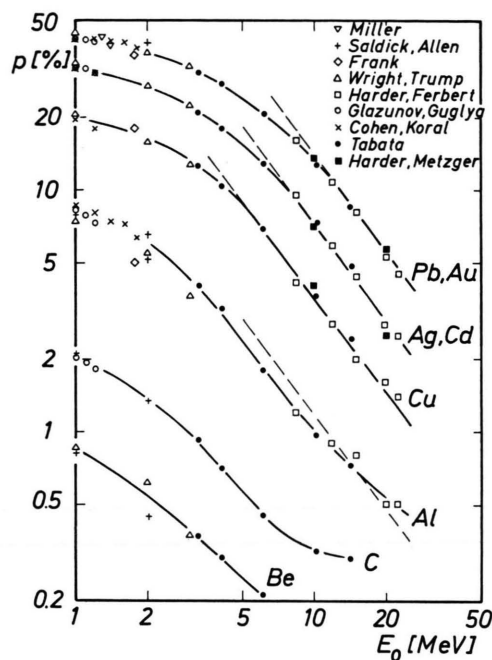


Fig. 2. Backscattering coefficients measured in the range 1 to 22 MeV and comparison to semi-empirical relation (2) indicated by straight dashed lines.

Table 1 shows the results of this experiment together with those of Harder and Ferbert, the latter containing a small correction applied posterior to the publication<sup>3</sup> and already mentioned by TABATA<sup>7</sup>. A plot of the experimental backscattering coefficients presently available above 1 MeV (except the results of DRESSEL) is shown in Fig. 2. The semi-empirical relation<sup>14</sup>

$$p = 2.2 (Z m_e c^2 / E_0)^{1.3} \quad (2)$$

proposed for the region of kinetic energies  $E_0 \gg m_e c^2$ , is shown for comparison ( $p$  in %). The  $Z/E_0$  dependence was postulated by FRANK<sup>1</sup> and further discussed in several papers<sup>3, 7, 15</sup>.

The agreement of the present, independent values with the main body of the previous results gives additional support to the conjecture that the cause of the discrepancy mentioned initially is due to Dressel's experiment. The following observations may be useful for further clarification: a) The spectra of backscattered electrons from lead at 9.76 resp. 10 MeV, measured by DRESSEL<sup>16</sup> and by HARDER<sup>17</sup>, do not display any significant difference in shape. b) The ratio of DRESSEL's backscattering coefficient to the interpolated value from Fig. 2 is nearly independent on target atomic number, but shows a characteristics dependence on electron energy\*.

<sup>14</sup> D. HARDER and G. POSCHET, Phys. Letters **24 B**, 519 [1967].

<sup>15</sup> D. HARDER, Biophysik **2**, 381 [1965].

<sup>16</sup> R. W. DRESSEL, Phys. Rev. **144**, 344 [1966].

<sup>17</sup> D. HARDER, in: Symp. on High-Energy Electrons, Springer, Berlin 1965.

\* In response to a preprint of this paper, DRESSEL has kindly informed us he has obtained evidence indicating that peripheral electrons from his entrance collimator have introduced a systematic error into his measurements resulting in backscattering coefficients which appear too large.