Energy	Intensity (quanta per fission)
27±3	0.45±0.15
101±3	—
119±3	—
142±5	—
207±5	0.107±0.052
295±5	0.026±0.020
360±10	0.085±0.050
490±10	0.071±0.037
590±15	0.101±0.047

and to G. N. Sofiev who helped in the construction of the pulse height analyzer.

1 Kinsey, Hanna and Van Patter, Can. J. Res. 26A, 79 (1948).

2 Progress in Nuclear Physics, II, London, 1952, pp. 150, 152.

3 R. B. Leachman, Paper presented at the International Conference on the Peaceful Uses of Atomic Energy, Geneva (1955).

4 Voitovetskii, Levin, and Marchenko, Report Institute of Atomic Energy, USSR (1955).

5 Artemenkov, Markov, Melnikov, Sofiev, Report Institute of Atomic Energy, USSR (1954).

6 R. B. Day, Paper presented at the International Conference on the Peaceful Uses of Atomic Energy, Geneva (1955).

7 Skliarevsky, Stepanov, Fomenkov, J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 256 (1957); Soviet Phys. JETP 5, 220 (1957).

Translated by A. Turkevich
58

SOVIET PHYSICS JETP VOLUME 5, NUMBER 2 SEPTEMBER, 1957

Investigation of Slow Electron Emission Induced by High Energy Protons

E. S. MIRONOV AND L. M. NEMENOV

Institute of Atomic Energy, Academy of Sciences, USSR

(Submitted to JETP editor September 24, 1956)

J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 269–273 (February, 1957)

An investigation has been carried out of the electron emission produced by high energy protons. The method is described. Values of the emission coefficients, γ_1 and γ_2 for aluminum and nickel in the energy range from 2 to 7.3 mev are presented.

INTRODUCTION

THE question of the interaction of positive ions with a metallic surface is not a new one. Most of the published work devoted to the dependence of the coefficient of emission γ on the energy of the impinging ions has involved relatively low energy ions. Thus for hydrogen and helium, the energy has not exceeded 400 kev[1]. Only in one investigation[2] has electron emission been observed using mercury ions having an energy of the order of 2.2 mev.

The present authors posed themselves the problem of studying the emission of electrons from thin foils both in the direction of the motion of protons (coefficient γ_1) and in the opposite direction (coefficient γ_2) At the same time it was proposed to determine the dependence of the coefficients γ_1 and γ_2 on the impinging proton energy in the interval from 2 to 7.3 mev. Aluminum and nickel were chosen to be the substances to be studied.

The source of the protons was a 1½ meter cyclotron having an external focused beam. The proton beam was obtained from hydrogen molecule ion acceleration up to approximately 14.7 mev with subsequent break-up of the molecule upon going through a thin aluminum foil. The beam of charged particles was taken to a distance of 12 m from the shielding wall of the cyclotron.

Work on measuring the beam strength of protons of the order of 7 mev showed that electron emission from the usual conducting materials amounted to 20–30% of the proton beam current. Calculations evaluating the expected magnitude of γ indicated values of the order of 30–40%. These facts determined to a certain extent the method used in the investigation.

1. METHOD OF MEASUREMENT

Fig. 1 shows the six principal methods used in measuring all the required quantities.

Method 1 is used to measure the total current,

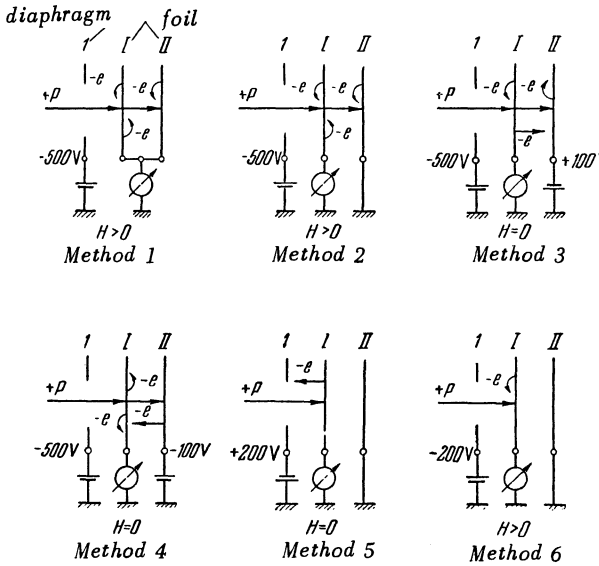

FIG. 1. Principal systems of measurement.

$I_1 = I_p'' + I_p''$, where I_p' is proton current entering the foil *I* and I_p'' is the proton current entering the foil *II*.

Method 2 is used to measure the current $I_2 = I_p'$ where I_p' is the proton current entering the foil *II*. The quantities measured in methods 1 and 2 are needed in order to establish the energy of the impinging protons.

Method 3 is used to measure the electron current i' from the foil *I* in the direction of motion of the proton beam.

Method 4 determines the electron current i'' from the foil *II* in the direction opposite to the proton beam motion.

Methods 5 and 6 are used to measure γ at the full energy of the proton beam. Foil *I* is chosen of such a thickness as to completely stop the proton beam.

The average energy of the incoming protons was determined by a range measurement in aluminum for which the range energy relation is known with high accuracy. Figure 2 shows schematically the arrangement used for the investigation. The fixed diaphragm *1* having a 20 × 30 mm opening defines the proton beam. Diaphragm *2* is also fixed and has a rectangular opening 25 × 35 mm in size and an insulated electrical lead for producing the necessary retarding potential. A series of metallic foils 44 × 44 mm can be placed successively into the insulated moveable frame *3*. Further on in the direction of the motion of the beam there is an insulated beam catcher *4*, into which a thick foil of the metal being studied can be placed. Before insertion of these foils they are carefully freed from grease. A special cold trap diminishes the possibility of oil vapors from the oil pumps reaching the foils. The pressure in the apparatus is of the order 1×10^{-5} mm Hg. A special clamp, not shown in the Figure, attached to the body of the apparatus makes possible the attachment of a small electromagnet for the production of a magnetic field. The main apparatus and all the parts are made from nonmagnetic materials.

All operations with the apparatus are carried out at a distance in view of the radiation hazards.

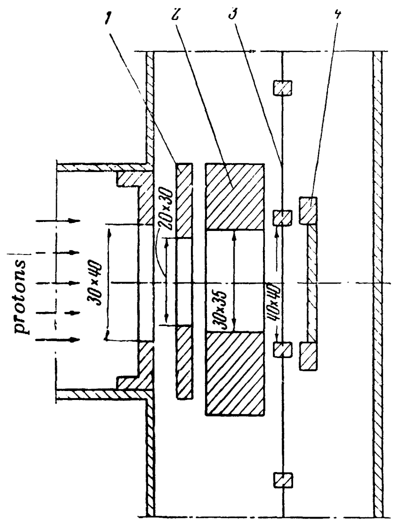

FIG. 2. Diagram of apparatus: Arrows at left indicate incoming protons.

2. ELECTRON–MEASURING APPARATUS

Figure 3 shows the electronics used in the measurements. A vacuum rectifier *2* furnishes a negative potential of 500 V with the help of a potentiometer R_{11} to the diaphragm 3. Foil *1* can be grounded by means of the switch Π_1 through one of the resistors having resistances between 5×10^4 and 10^6 Ω. The voltage drop across the resistor was measured using a direct current amplifier with a mechanical modulator. The output of the amplifier was fed into an indicating instrument.

In order to establish the sensitivity of the amplifier there was assembled an apparatus giving calibrated output which consisted of the dividers R_6, R_7, and the rectifier *3*. Using the switch Π_2 it was possible to pick out any one of the six principal schemes of measurement illustrated in Fig. 1.

The electromagnet pictured in Fig. 3 was powered from a direct current circuit through a variable resistor R_{13}. The capacitator C_4 served to remove residual magnetism. On opening the switch P_1 there starts a transient consisting of the exchange of energy between the capacitator C_4 and the inductance of the electromagnet windings. During this process the current in the magnet windings has a damped sinusoidal character. The result of this process is the complete demagnetization of the iron of the electromagnet.

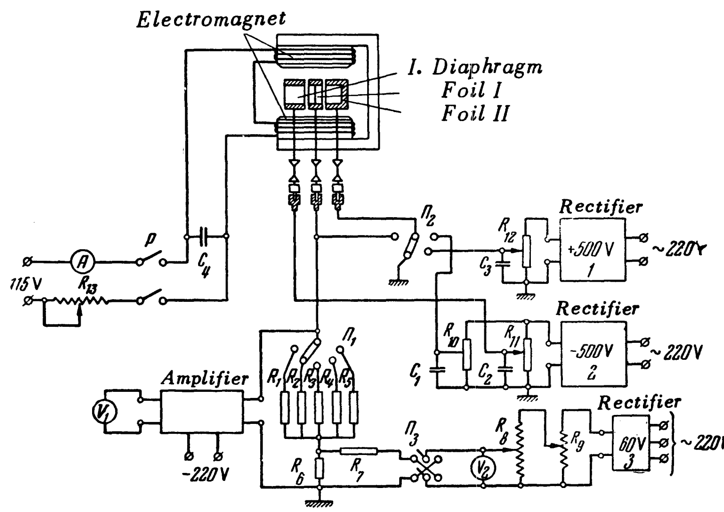

FIG. 3. Electron-measuring circuit.

3. RESULTS OF THE MEASUREMENTS

Preliminary experiments showed that even at magnetic fields H of the order of 200 Oe there was practically no electronic component to the current. In the final experiments the field had values up to 800 Oe. It was likewise shown that, in the measurement of the electronic current according to schemes 3 and 4, it was sufficient to have foil *II* at a potential of the proper sign of the order of 25 V. In practice 100 V was applied. In order to repel the electrons flying out from foil *I* in the direction opposite to the motion to the protons toward diaphragm *3*, it was sufficient to apply a potential of the order of –50 V. In practice foil *III* was placed at –500 V. The measurements were repeated three times; moreover, each measurement carried out according to schemes 2, 3, and 4 leads to a measurement of the current according to scheme 1 (the measurement of the total proton current impinging on the two foils). After each experiment the amplifier was calibrated with the generating equipment.

Figures 4 and 5 show the dependence of the coefficients γ_1 and γ_2 on the energy of the incoming protons for aluminum and nickel.* The results obtained show that, in the proton energy range from 2–7.3 mev, the coefficients of electron emission for aluminum and nickel do not differ much and change on the average from 1.8 to 0.5. The number of electrons knocked out in the beam direction is larger than the number knocked out in the direction opposite to the beam motion. This difference is observed for both aluminum and nickel and amounts to about 20%. The energy of the protons coming from the cyclotron was determined from the average range in aluminum. The accuracy of this measurement is ± 200 kev. Evaluation of the errors in measurement of the coefficients γ lead to maximum possible errors not exceeding ± 10%.

All these experiments were carried out in 1953.

In conclusion the authors thank Academician L. A. Artsimovich for discussions of the experiment and the results. At the same time, the authors take this opportunity to express their gratitude to V. I. Bernashevsky and to K. N. Petrov* who constructed the apparatus for this investigation.

*The range energy curve for nickel was kindly furnished us by B. V. Rybakov.

*Deceased.

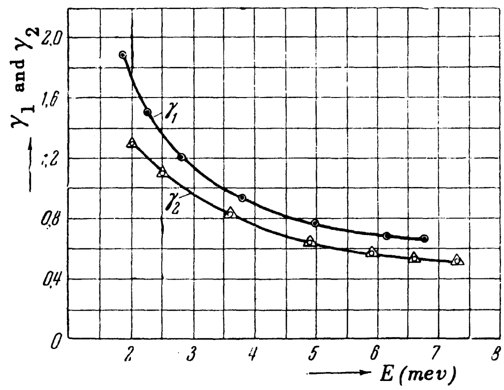

FIG. 4. Proton energy dependence of the coefficients of electron emission γ_1 and γ_2 for aluminum.

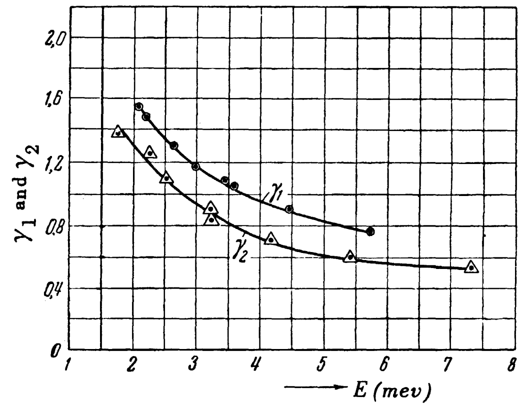

FIG. 5. Proton energy dependence of the coefficients of electron emission γ_1 and γ_2 for nickel.

1 Hill, Buechner, Clark and Fisk, Phys. Rev. 55,463 (1939).
2 A. Linford, Phys. Rev. 47, 279 (1935).

Translated by A. Turkevich
59