EFFICIENCY OF SECONDARY ELECTRON EMISSION MONITORS FOR 70 MeV ELECTRONS [*]

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SUMMARY

The secondary electron emission coefficient from several elements in the form of thin foils has been measured using 70 MeV electrons as bombarding particles.

Using foils with different atomic numbers, it was found that the secondary emission coefficient per target electron in the metal is noticeably larger for light elements, especially in cases of beryllium and aluminum. This indicates that metal oxide on the foil surface (Malter effect) is playing a dominant role in the secondary emission of these metals.

For other metals, the experimental results seem to indicate a relatively small variation in the secondary emission coefficient per target electron, less than that predicted by V. J. Vanhuyse and R. E. Van de Vijver, but with the same general behavior.

The lack of thickness dependence in the case of tantalum foils is in agreement with the extensive experimental work of B. Planskoy and with the theoretical treatment of the secondary emission by Aggson.

The secondary electron emission coefficients will be given for the measured foils and the experimental values will be compared with the existing theories.

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INTRODUCTION

The purpose of this paper is to summarize the experimental results on the secondary electron emission yields from thin metal foils bombarded with a high energy electron beam. This study was started as a search for a stable and accurate beam current monitor for high energy (10 MeV - 20 GeV) and high intensity (10^{-11} - 10^{-4} amps) electron beams.

EXPERIMENTAL RESULTS

Experimental Setup

For the experimental work to study the secondary electron emission properties of thin metal foils bombarded with electrons of 70 MeV of energy, the Stanford Mark IV linear accelerator was used. The configuration of the apparatus used in the experiment is shown schematically in Fig. 1. The electron beam from the accelerator was energy analyzed (energy resolution $\approx 1\%$) by a magnetic deflection system, passed through two SEM's built from different foils, and finally collected in a Faraday cup. The efficiency (Y) of the different foils is given as the ratio of charge integrated on a condenser to the charge collected in the Faraday cup. The Faraday cup was designed to catch more than 99% of the electrons in the beam.

The experiments were run under high vacuum conditions, usually 3×10^{-7} torr or better. The foils in the monitor were cleaned and the whole monitor, built from stainless steel, was baked out under vacuum for at least 12 hours.[1]

Yield Dependence on Atomic Number

Twelve different foils have been measured in this secondary emission study: Beryllium, aluminum, titanium, 320 stainless steel, nickel, copper,

molybdenum, rhodium, silver, tantalum, wolfram, and gold. The results are displayed in Fig. 2 which shows the efficiency of each element as compared to the efficiency of gold. The upper curve shows the theoretical prediction of V. J. Vanhuyse and R. E. Van de Vijver.[2] A more detailed comparison of the experimental results with the theoretical predictions will be treated later. The interesting aspects of secondary emission are more clearly seen in Fig. 3. Here the measured relative yields (Efficiency X/Efficiency Au) are divided by the electron density $\delta N_0 Z/A$ in the foils, where N_0 is Avogadro's number, δ is the density of the foil, Z is the atomic number, and A is the atomic weight. This curve shows the efficiency of secondary electron emission per target electron. The light elements, especially beryllium and aluminum, are noticeably more efficient elements than theory predicts. Beginning with titanium and for Z higher than titanium, the efficiency is in good agreement with theory. Because both beryllium and aluminum have oxide coatings under normal conditions, this may indicate that the oxide is playing a dominant role in the secondary emission of these metals. Except for these two metal foils, however, the experimental results seem to indicate a relatively small variation in efficiency per electron among elements, less than that predicted by theory but with the same general behavior.

Thickness Dependence

The secondary emission yield was measured for tantalum foils 1.0 mil and 2.4 mils thick. No significant difference was observed in their secondary emission for collection voltages between 1 and 500 volts. This is a direct contradiction to the theory of Vanhuyse and Van de Vijver, which predicts that the total yield of a given foil goes as $Y = F_1$ (energy, metal constants) $+ F_2$ (energy, metal constants) (thickness)$^{\frac{1}{2}}$ where F_2 is larger than F_1

for all measured elements. For tantalum, this theory predicts that

$$\frac{Y_{Ta} \ (2.4 \ mil)}{Y_{Ta} \ (1.0 \ mil)} = 1.48$$

This lack of thickness dependence is in agreement with the extensive experimental works of B. Planskoy[3] on aluminum and with the theoretical treatment of secondary electron emission by Th. L. Aggson.[4]

Surface Effects

To investigate the effect of the beam on the surface layer of the foil, the yield was measured with different beam currents and varying collector voltage. In these runs the foil surface was "baked" out for an hour by beams of different currents values and the yield was recorded as a function of the collection voltage. Figure 4 shows the relative efficiency as a function of the collection voltage after an hour of baking with different intensity beams. It is evident from this figure that the yield changed at low collection voltage values; i.e., the energy spectrum of the secondary electrons is altered by the change in the surface layer, but the high voltage yield values did not change appreciably. This indicates that the low energy part of the secondary electron emission spectrum is a very sensitive function of the characteristics of the surface layer, but it does not influence the efficiency of the SEM when the collection voltage is high enough.

Figures 5 and 6 give the variation in efficiency as a function of collection voltage divided by the corresponding efficiency of gold and aluminum at the same voltage. These results were all obtained at energies around 70 MeV with average currents between 3 and 5 μA. By taking the derivatives of these curves one can determine the energy spectrum of the secondary electrons from different metal foils as compared to gold and aluminum. Most of

the electrons seem to be emitted with energies below 30 eV, which is what one should expect if the secondary emission is truly a surface phenomena, as seems to follow from the thickness dependance measurements.

There was no observed variation in the efficiency of secondary electron emission with currents ranging from 0.1 μA to 20 μA. It was difficult to get consistent data below 0.1 μA because of the long integrating times involved and the galvanic currents of this magnitude observed on the Faraday cup itself from the cooling water. One of the most interesting aspects of the secondary emission is the small decrease in efficiency of the collection process from a maximum with increasing collection voltage. This effect has been explained by Aggson as a manifestation of the Malter effect due to the surface contamination by vacuum pump oils and the oxide coatings. In this study all the metal foils showed this effect to some degree, although the cleanest metal surfaces, particularly molybdenum, gold and tantalum, show exactly the same effect when compared to each other in the same run. For example, in Fig. 5 the efficiency of molybdenum foil divided by the efficiency of the gold foil in the same SEM during the same run remains constant above a 20-volt collection voltage. This would appear to indicate either that the effect is due to the experimental setup, or that both metals were contaminated exactly the same, possibly by vacuum pump oil.

High Energy Secondary Electrons

The properties of the high energy secondary electrons (knock-on electrons or delta rays) emitted from metal foils have been investigated by Shatas, Marshall and Pomerantz[5] and recently by B. Planskoy.[3] It was found that the percentage of the high energy secondary electrons in the total yield depends on the thickness as $t^{\frac{1}{2}}$, and it is not influenced by the surface condition

of the emitting foil. In this experiment the fraction of the high energy electrons emitted from the foil was estimated from the following measurements. On a three-element SEM the collector voltages were applied with three different polarities, as shown in Figs. 7a, 7b, and 7c. Figure 7a shows the normal operation of a three-element SEM; in this case the electron collection efficiency is the largest and the measured yield divided by two gives the efficiency per active foil surface. I_f is the high energy component of the secondary emission current emitted by foil and unaffected by the field.

A fraction α of this high energy secondary electron current is stopped by the following foil. The arrows on Fig. 7 show the directions of the electron currents and the letters F and B refer to the front or back side emission currents relative to the beam direction.

Figure 7b shows the secondary electron currents when the first foil was negative with respect to the center and the third was at positive potential. Without high energy components in the emission, one would expect zero efficiency with this polarity similar to the case where the first foil was positive and the third was negative with respect to the center foil (Fig. 7c). The experimental results from these measurements for Zr and Rd are shown in Fig. 8, where the electron collection efficiency on the center foil is plotted versus the collection voltage. It can be seen from these curves that the value of the collection voltage does not markedly change the collection efficiency in the low voltage region as it does in the case of the low energy component. Using the measured electron collection efficiency, the fraction of the high energy component in the total electron collection efficiency can be estimated as

$$R_{coll} = \frac{\frac{1}{2}\left(\frac{Y_{Rd+-} + Y_{Rd-+}}{2}\right)}{Y_{Rd}} \approx 3.6\%$$

This high energy electron collection efficiency might be interpreted as the lower limit for the ratio of the high to low energy electrons in the total secondary electron emission.

LIST OF REFERENCES

1. S. A. Blankenburg, J. K. Cobb and J. J. Muray, IEEE Particle Accelerator Conference, Washington, D.C., March 10-12 (1965).

   J. K. Cobb, J. J. Muray SLAC Report (to be published.)

2. V. J. Vanhuyse and P.E. Van de Vijver, Nuc. Instr. and Meth. 15, 63 (1962).

3. B. Planskoy, Nuc. Instr. and Meth. 24, 172 (1963).

4. Th. L. Aggson, Report LAL-1028, Laboratoire de l'accèlerateur linèaire, Orsay, France (1962).

5. R. A. Shatas, J. F. Marshall and M. A. Pomerantz, Phys. Rev. 96, 1199 (1954).

LIST OF FIGURES

COLLECTION
VOLTAGE
POWER
SUPPLY

0 - 500 VOLTS

0 - 500 VOLTS

e⁻

BEAM
70 MeV
(electrons)

FARADAY
CUP

CURRENT
INTEGRATOR

CURRENT
INTEGRATOR

CURRENT
INTEGRATOR

FIG. I - SCHEMATIC OF EXPERIMENTAL SETUP

231-5-A
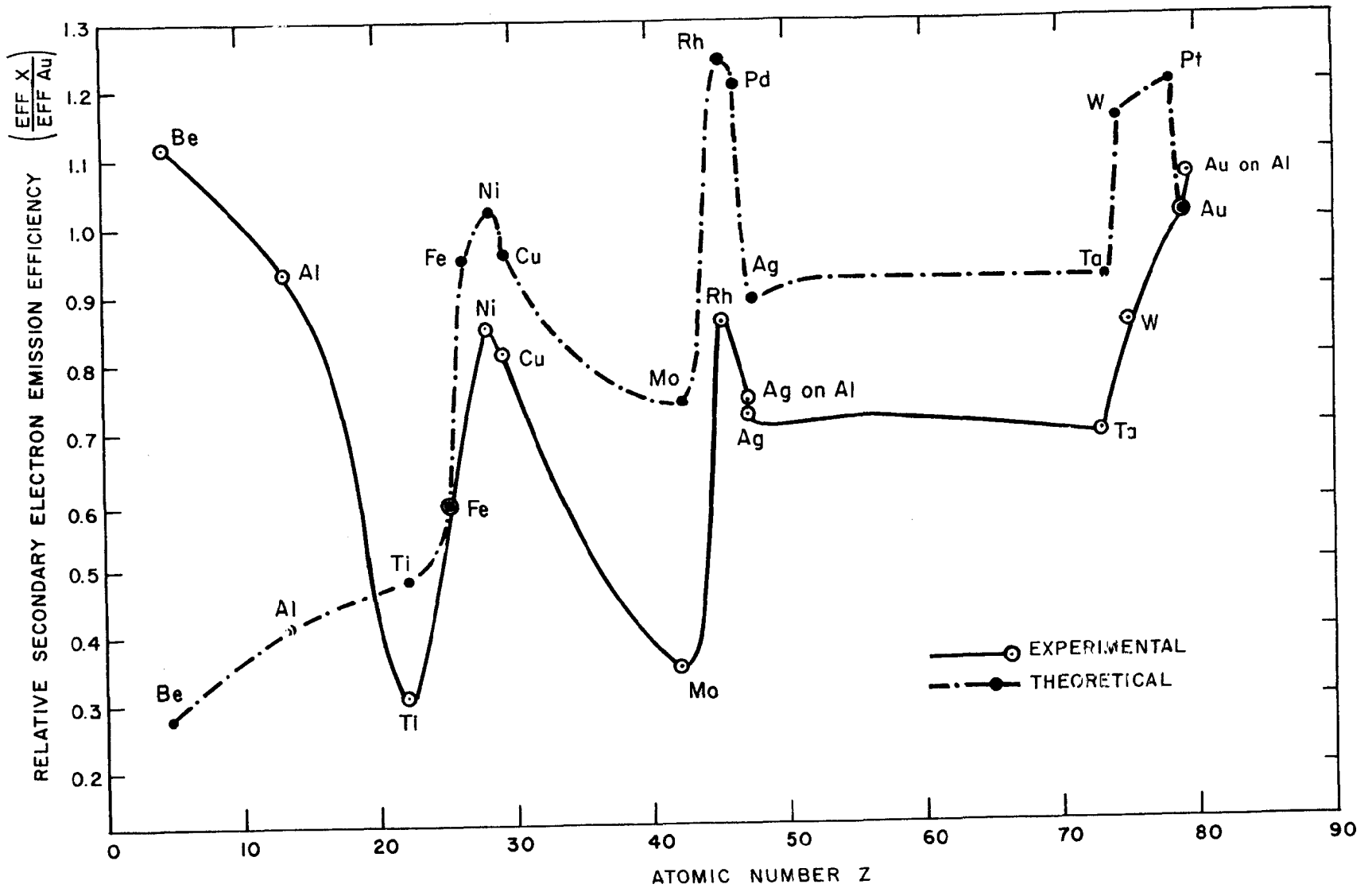
FIG. 2 – RELATIVE EFFICIENCY VS. ATOMIC NUMBER

231-6-A
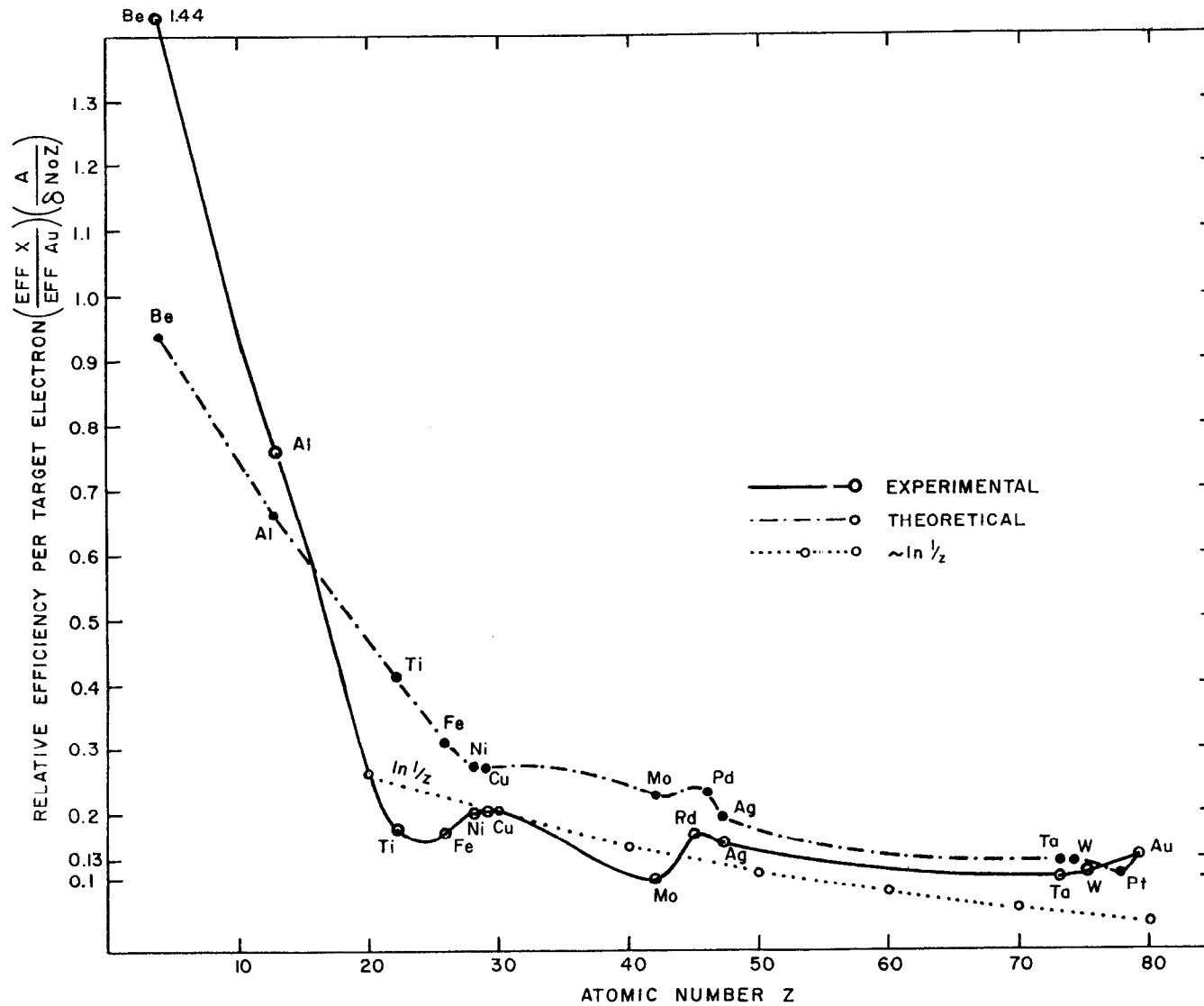
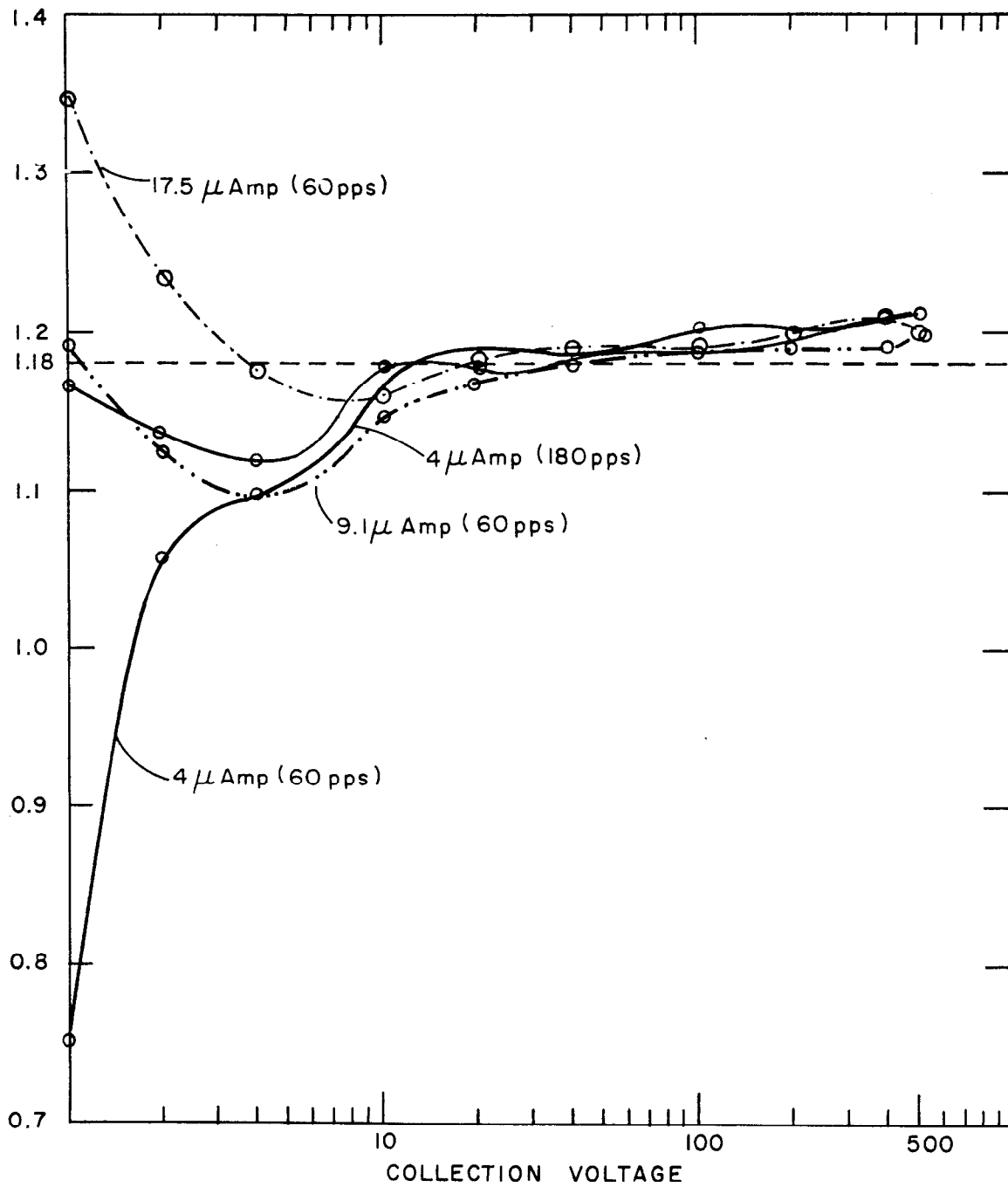FIG. 3 - RELATIVE EFFICIENCY PER TARGET ELECTRON VS. ATOMIC NUMBER

231-7-A

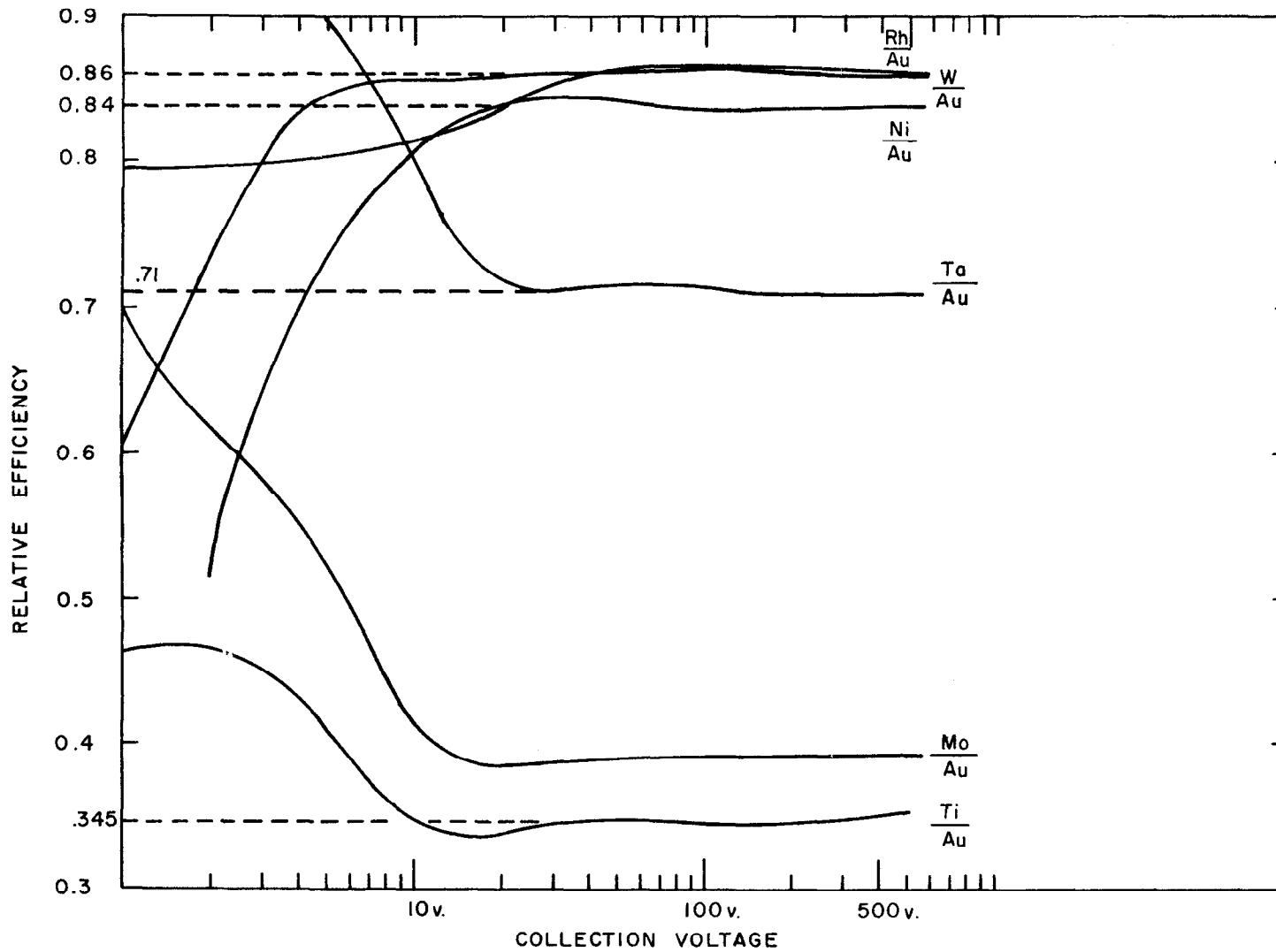FIG. 4 - $\dfrac{Y_{Be}}{Y_{Al}}$ VS. COLLECTION VOLTAGE AT 70 Mev.

231-8-A

FIG. 5 - RELATIVE EFFICIENCY vs COLLECTION VOLTAGE.
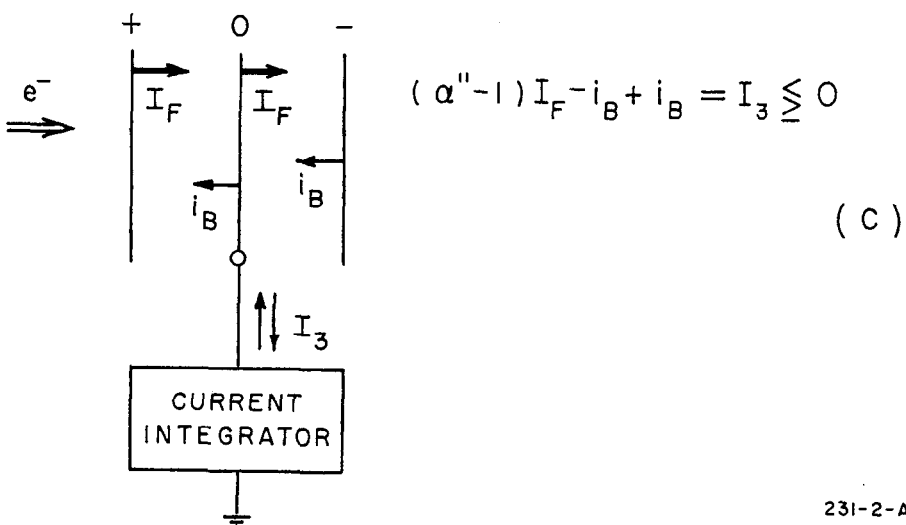PRIMARY ELECTRON ENERGY 70 MeV.

231-9-A
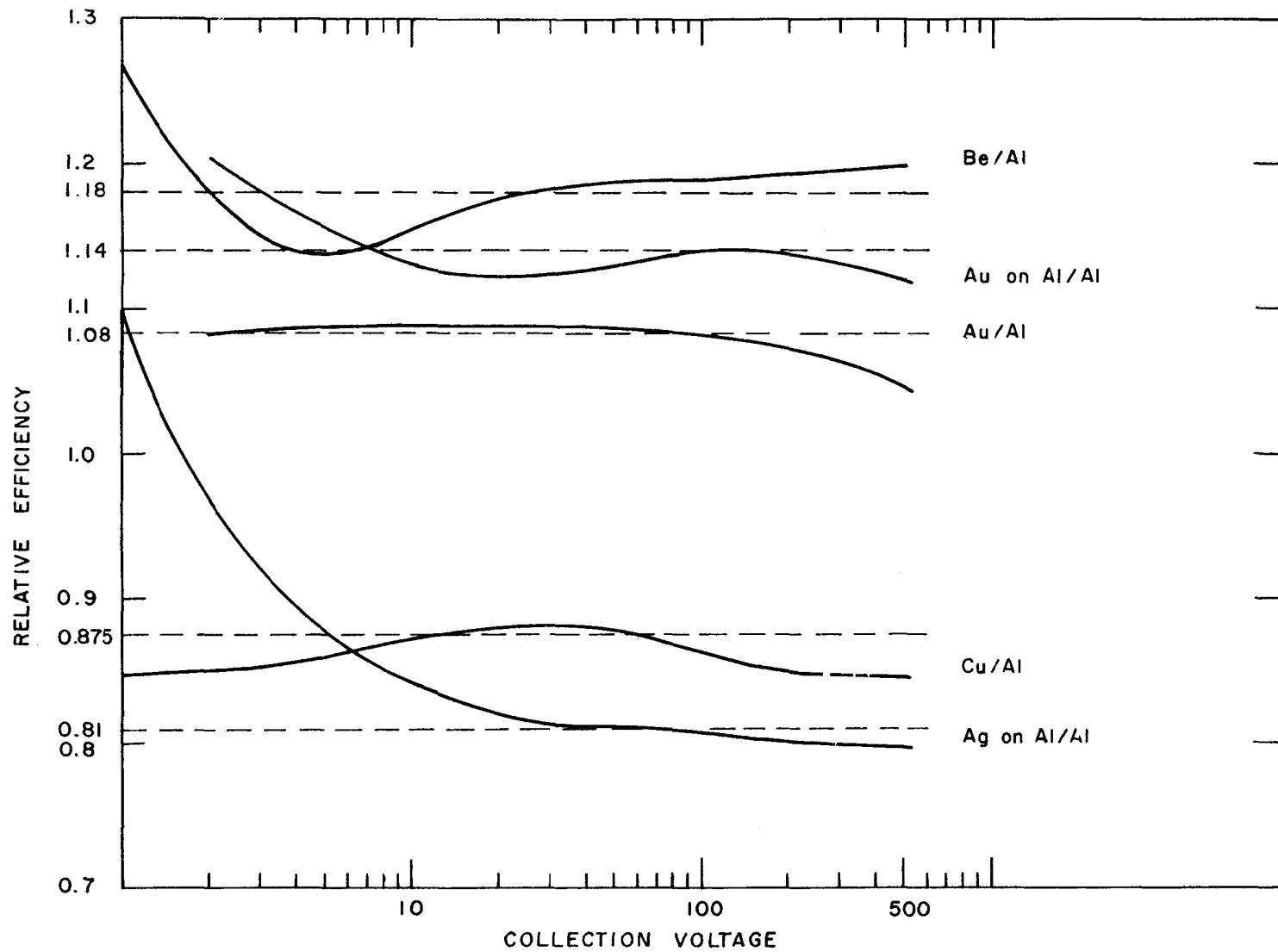
FIG. 6 - RELATIVE EFFICIENCY VS. COLLECTION VOLTAGE
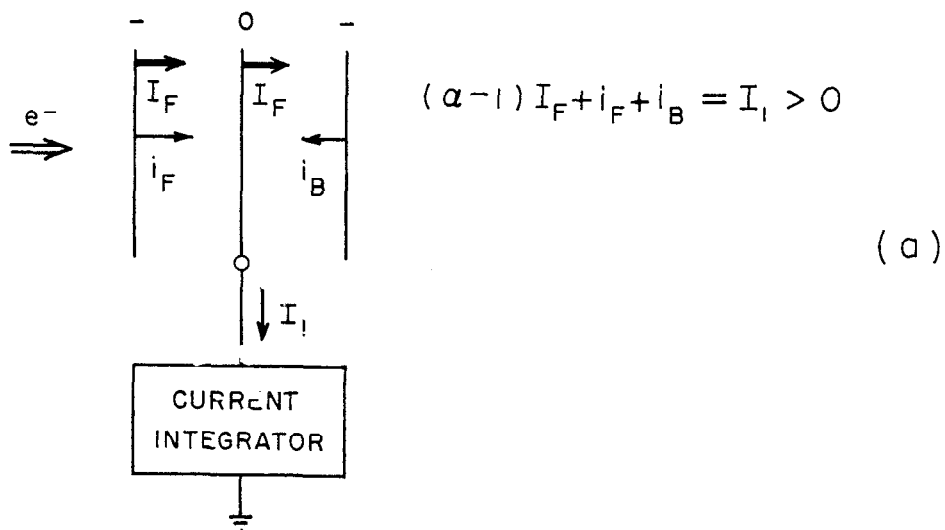
231-6-A

$(a-1)I_F + i_F + i_B = I_1 > 0$

(a)

$(a'-1)I_F - i_F + i_F = I_2 < 0$

(b)

$(a''-1)I_F - i_B + i_B = I_3 \lessgtr 0$

(c)
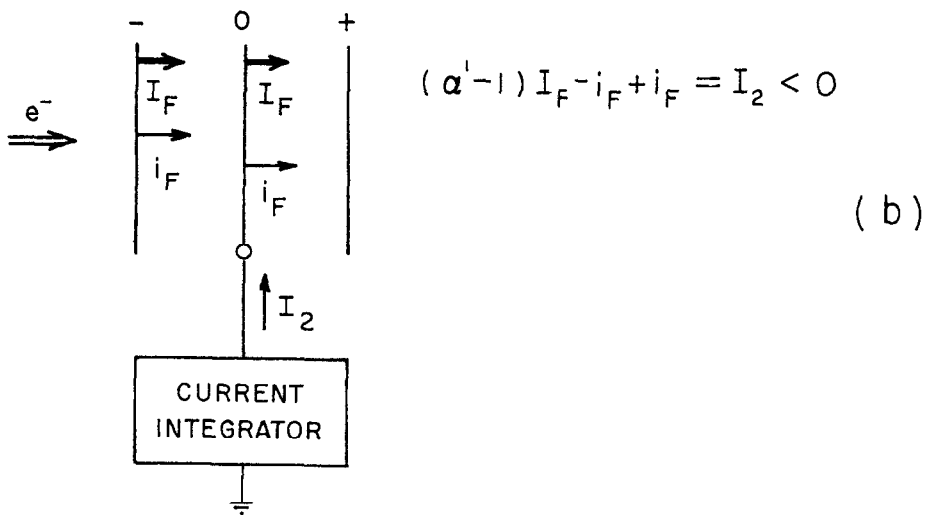
231-2-A

FIG.7 - ARRANGEMENTS FOR MEASURING THE HIGH ENERGY
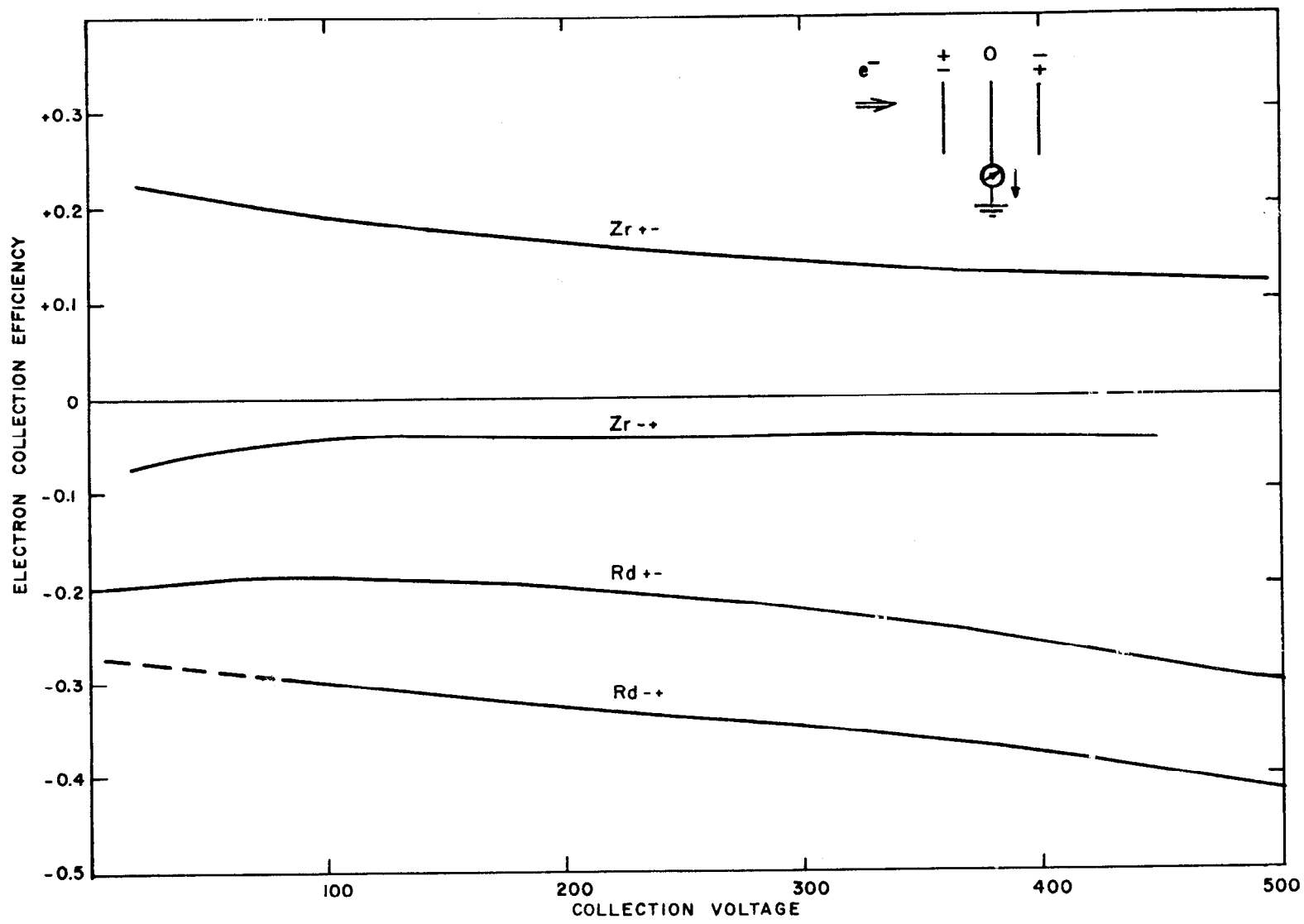COMPONENTS IN THE SECONDARY ELECTRON EMISSION.

FIG. 8 – ELECTRON COLLECTION EFFICIENCY VS. COLLECTION VOLTAGE

231-11-A