ELECTRON IMPACT DESORPTION FROM VACUUM SURFACES

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March 1974

PLP 552

Plasma Studies

University of Wisconsin

Neutrals play important roles in many plasma devices, both as sources for plasma particles (via ionizing collisions) and as sinks for energy (e.g., via charge exchange collisions and line radiation). A careful computer code plasma model (such as that developed by J. C. Sprott[1] and J. R. Patau[2]) for existing experiments with low to medium range electron and ion temperatures gives results that differ considerably from experimental results unless neutral influx is properly treated.

The source of neutral influx to the plasma is apparently largely from the walls and other solid material which are bombarded by plasma particles. For the octupoles' cold ion and warm electron plasmas, electrons colliding with walls, hoops and supports may release a significant fraction of the neutral reflux during a discharge. Therefore, an experimental measurement of desorption yield due to electron impact on vacuum surfaces is desirable.

A literature search reveals vast quantities of data for monolayers of known gas adsorbed on otherwise atomically clean tungsten, molybdenum and nickel sufraces. (See Redhead, Hobson, and Kornelsen[3] for a good review and further references.) For those conditions, the electron impact desorption (EID) cross-sections tend to follow ionization cross-sections, except for usually being much smaller.

However, the surface conditions in plasma physics experiments can hardly be called atomically clean. Typically, we have many, perhaps hundreds, of layers of unknown adsorbed gas on aluminum, copper, stainless steel, glass, ceramic, etc.. Little EID work has been done for such dirty, unknown conditions as we are most interested in. Table I lists the references and quoted results that we have been able to find.

[Since doing the presently reported work, we have been informed of an interesting series of experiments by R. E. Clausing,[7] who has obtained results similar to ours where comparison is possible, and has also done other exploratory work with EID on dirty surfaces.]

Since relevant experimental information is so meager, an experiment has been set up to attempt to measure desorption yield due to electrons hitting a target surface, as a function of electron energy.

A top view of the apparatus is shown sketched in Fig. 1. A coiled tungsten filament with water-cooled leads is the electron source. It is placed usually two inches or less from the target at the closest point. The filament draws a current of five to seven amperes during usual operation, and has a corresponding voltage drop of seven to fourteen volts. The target is a metal plate intended to be larger than the cross-section of the electron beam. A potential drop from target to filament accelerates the electrons up to 13.5 kev. Electron currents up to 20 ma are drawn.

A residual gas analyzer can be used to identify the residual gas in the vacuum chamber, and to measure the relative change in partial pressure of any gas due to EID. The residual gas at the base pressure of 1×10^{-7} torr turned out to be mostly H_2 and secondly H_2O, after initial pumpdown starting with ordinary air.

The experimental quantity obtained is molecular yield in molecules per electron incident on the target. The quantities measured are electron current to the target, I_t, and the change in pressure, Δp, between the equilibrium conditions, the first with the filament hot but the target at ground, and the second with positive potential applied to the target.

For the first equilibrium condition,

$$\frac{Sp_o}{V} = \left.\frac{dp}{dt}\right|_{outgas}, \tag{1}$$

where S is the measured pump speed, p_o is the base pressure and V is the vacuum chamber volume. The right-hand side is the outgassing rate of all surfaces with the filament hot.

For the second equilibrium condition, electron-caused desorption adds another term to the right-hand side, making equilibrium pressure higher, giving

$$\frac{Sp}{V} = \left.\frac{dp}{dt}\right|_{outgas} + \left.\frac{dp}{dt}\right|_{EID} . \tag{2}$$

Assuming pump speed and outgassing rate to remain essentially constant over the small pressure range involved ($\Delta p \lesssim 10^{-6}$ torr), subtracting Eq. (1) from (2) gives:

$$\frac{S}{V}\underbrace{(p - p_o)}_{\Delta p} = \left.\frac{dp}{dt}\right|_{EID} = \frac{KT}{V}\left.\frac{dN}{dt}\right|_{EID} . \tag{3}$$

Now $\left.\frac{dN}{dt}\right|_{EID}$ is the rate at which neutrals are liberated from the target due to bombardment by the energetic electrons. Dividing $\left.\frac{dN}{dt}\right|_{EID}$ by the electron current to the target, I_t, gives a formula for EID yield in terms of measurable quantities:

$$\frac{\left.\frac{dN}{dt}\right|_{EID}}{I_t} = \frac{S\Delta p}{I_t}\frac{1}{KT} . \tag{4}$$

The temperature in the proportionality factor is the temperature assumed in the ion gauge calibration, i.e., T = "room temperature" ≡ 293° K.

The measurement of pumping speed S is important because this knowledge allows giving the experimental results in absolute terms of molecules/electron instead of the arbitrary units of $\Delta p/I_t$. Pumping speed is measured by filling the small inlet tank to a high pressure (~ atmospheric) and pumping through a small needle valve leak to the main chamber. The pressure change in the small tank, measured with a mercury manometer, is much larger than the pressure change in the main chamber, for the same time interval. Thus one may write:

$$\frac{Sp_m}{V_s} = \frac{dp_s}{dt} , \tag{5}$$

where subscript m refers to the main chamber and subscript s refers to the small tank. Rearranging Eq. (5) shows S in a convenient form as a function of measurable quantities:

$$S = V_s \frac{p_s}{p_m} \frac{1}{p_s} \frac{dp_s}{dt} . \tag{6}$$

The decay of p_s is a close approximation to an exponential.

The initial bombardment of a target freshly exposed to air for a long time previous to pump-down produces yields significantly higher than the ones to be reported here. This high level yield decreases on a time scale of the order of tens of seconds. This initial high rate of desorption is probably due to weakly absorbed gases.

The yields measured and reported here correspond to those from a surface cleaned of the easily desorbed gases, and probably represents more nearly a discharge cleaned Tokamak than an octupole. These yields vary slowly enough with time of bombardment to be measured using the equilibrium-to-equilibrium technique described above.

These preliminary results for EID yield as a function of electron energy are shown on log-log plots in Figs. 2, 3, and 4.

The first two graphs show data taken in vacuum pumped down from air. Later use of the residual gas analyzer showed that the main components of the residual gas are H_2 and H_2O. The sample whose data is shown in Fig. 2, was a piece of scrap aluminum wiped clean with alcohol and acetone, but otherwise untreated. The base pressure was 5×10^{-7} torr.

The upper series of data points was for the target relatively freshly exposed to air, but after the initial high yield level had settled to a constant. The lower series of data was taken after a total of three bombardment cycles (taking yield data for energies up to 13.5 Kev) and eight days of pumping. The decrease in yield for the second set of data shown is attributed to coverage depletion due to natural outgassing, perhaps speeded up a little by the electron bombardment. The lines drawn through each set of data have slope unity.

The second graph (Fig. 3) shows EID yield from a newly cut piece of alloy #6061 aluminum. The base pressure has been reduced to 1×10^{-7} torr by installing a LN_2 cold finger above the oil diffusion pump. Again we see the influence of natural outgassing on yields in comparing the first data taken with that taken four pumping days later. Below electron energies of about 100 ev there seems to be departure from the approximate linear

trend. The line through the upper data points has a slope of .9 and that through the lower points has a slope of unity.

The last graph (Fig. 4) shows data for the same target. But before taking these data, the pressure had been raised to 1×10^{-5} torr, or 100 times base pressure, for 24 hours by admitting hydrogen through a controlled leak. The purpose of the high H_2 partial pressure was to try to simulate wall conditions in experimental devices using hydrogen plasmas. The yields measured are in the same range as on the previous graph.

The line shown has slope .8. Circles indicate that the distance between the target and the closest part of the hot filament was one inch; and squares, one-quarter inch.

The two asterisks indicate data points where the residual gas analyser was set at the H_2 peak. This peak height was seen to increase during bombardment, but a quantitative interpretation is difficult to make.

Comparing the first target of scrap aluminum with the second target of #6061 aluminum, one notes that the first gave much higher yields. At this point in the research, one can only speculate about the reason. Our opinion is that, due to lack of a cold finger when the first target was being studied, much of the adsorbed gas was diffusion pump oil, which tends to give relatively high yields, as noted also by Garbe, Bernadini and Clausing.

Tentative conclusions may be drawn from these initial results. There seems to be a nearly linear dependence of yield on electron energy between about 100 ev and 10 Kev. The magnitude of yield can vary widely between

different target specimens. This magnitude is seen to decrease as time of pumping increases and possibly also as electron bombardment time increases.

The most important work that can readily be done in the near future is the following:

1) Measure target temperature before and after bombardment.
2) Identify the main desorbing gases.
3) Obtain data for different targets.
4) Try different target treatments.
5) Observe time rate of decrease of yield as bombardment continues for a long time.

Other relevant work would be:

1) Following the initial high yield rate as a function of time and electron energy for a "freshly exposed" target;
2) Proposing and checking a theory explaining the observed results;
3) Separating coverage depletion effects due to pumping and due to electron bombardment;
4) Extending the measurements over a wider range of electron energies.

author	S. Garbe[4]	M. Bernadini[5]	Todd, et al[6]
surface	DC 704 oil adsorbed on Mo	diffusion pump oil adsorbed on 304 S.S.	5 types of glass
e^- energy	70 - 150 ev		20 Kev
EID yield	$5x10^{-2}$ H_2 molecules/e^-	$5x10^{-3}$ H_2 molecules/e^-	mostly O_2 (95%)

Table I. References on results of electron bombardment of dirty vacuum surfaces.

References

1. J. C. Sprott, "Zero Dimensional Steady-State Plasma Simulation Computer Code," PLP 535 (1973).
2. J. R. Patau and J. C. Sprott, APS Bulletin 18, 1352 (Oct. 1973).
3. P. A. Redhead, J. P. Hobson, and E. V. Kornelsen, The Physical Basis of Ultrahigh Vacuum, Chapter 4, Chapman and Hall, London, 1968.
4. S. Garbe, Vakuum Technik 12, 201 (1963).
5. M. Bernadini, Trans. 3rd. Int. Vac. Cong. 2, 481 (1965).
6. B. J. Todd, J. L. Lineweaver, and J. T. Kerr, Jour. App. Physics 31, 51 (1960).
7. R. E. Clausing, "Exploratory Experiments Concerning the Desorption of Gases by Bombardment with Electrons," ORNL-TM-1166, Oak Ridge National Laboratory, 1964.

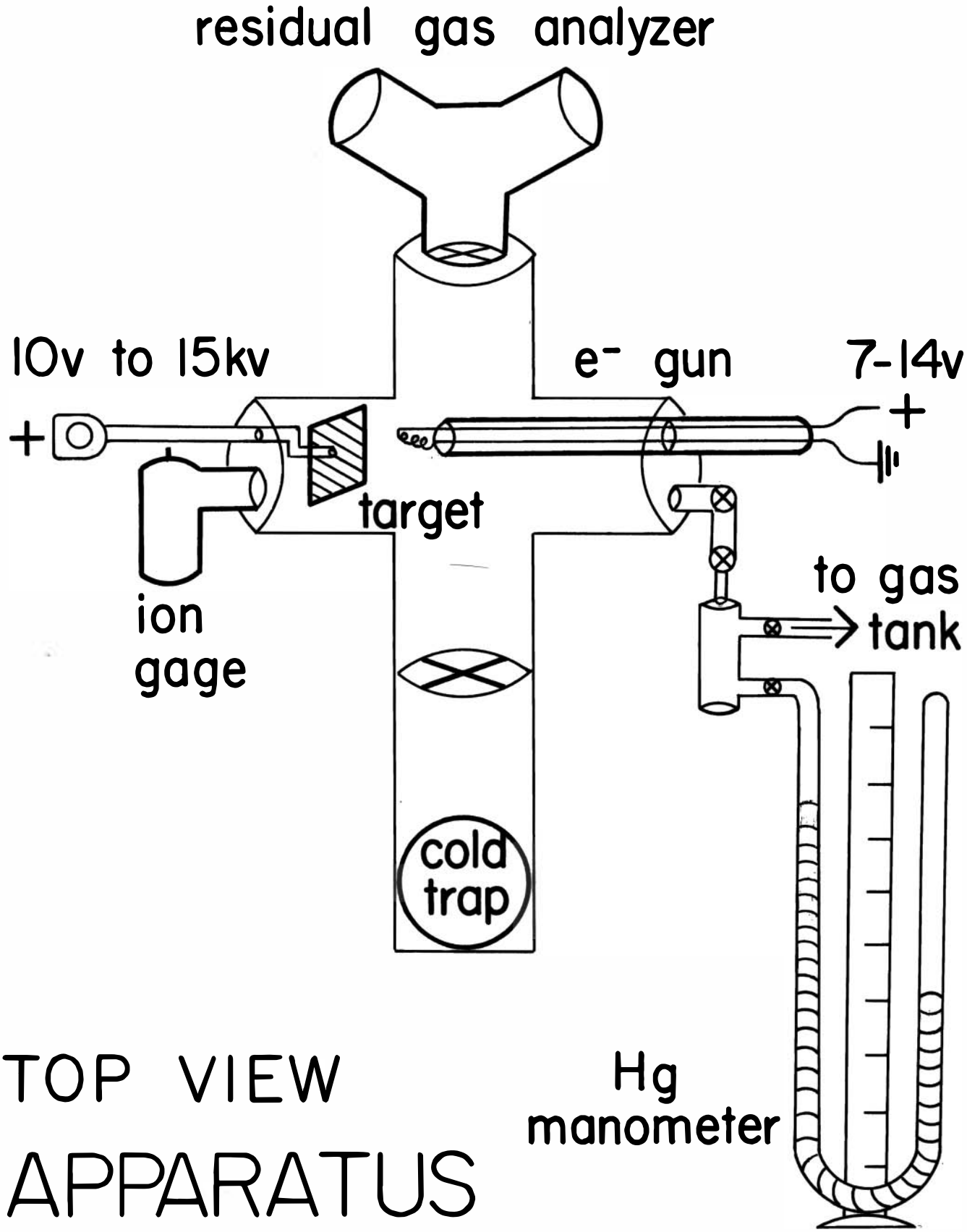

Figure 1. Sketch of the experimental apparatus.

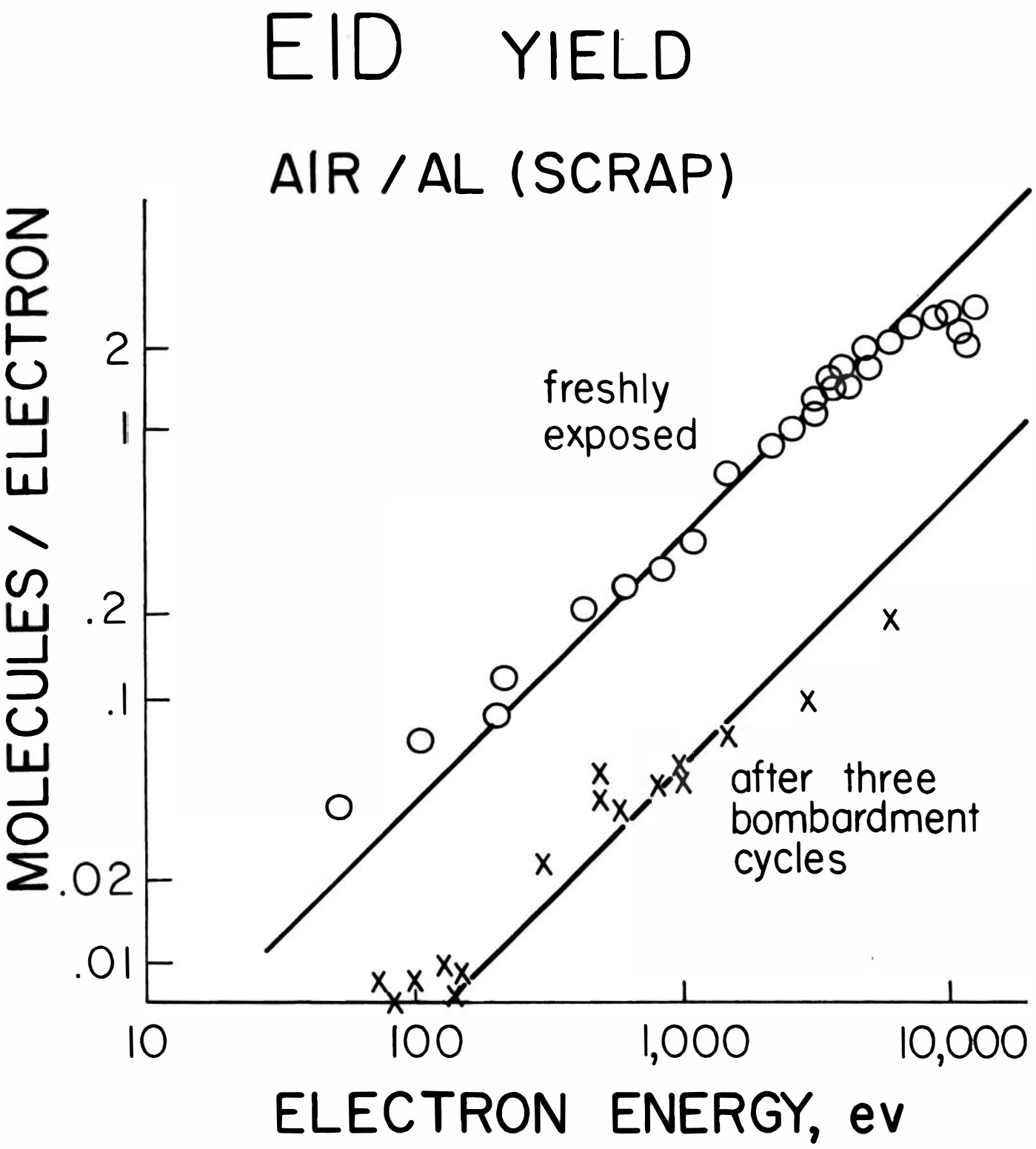

Figure 2. EID yield versus incident electron energy for a clean scrap aluminum sample, with a 5×10^{-7} torr base pressure vacuum pumped down from air.

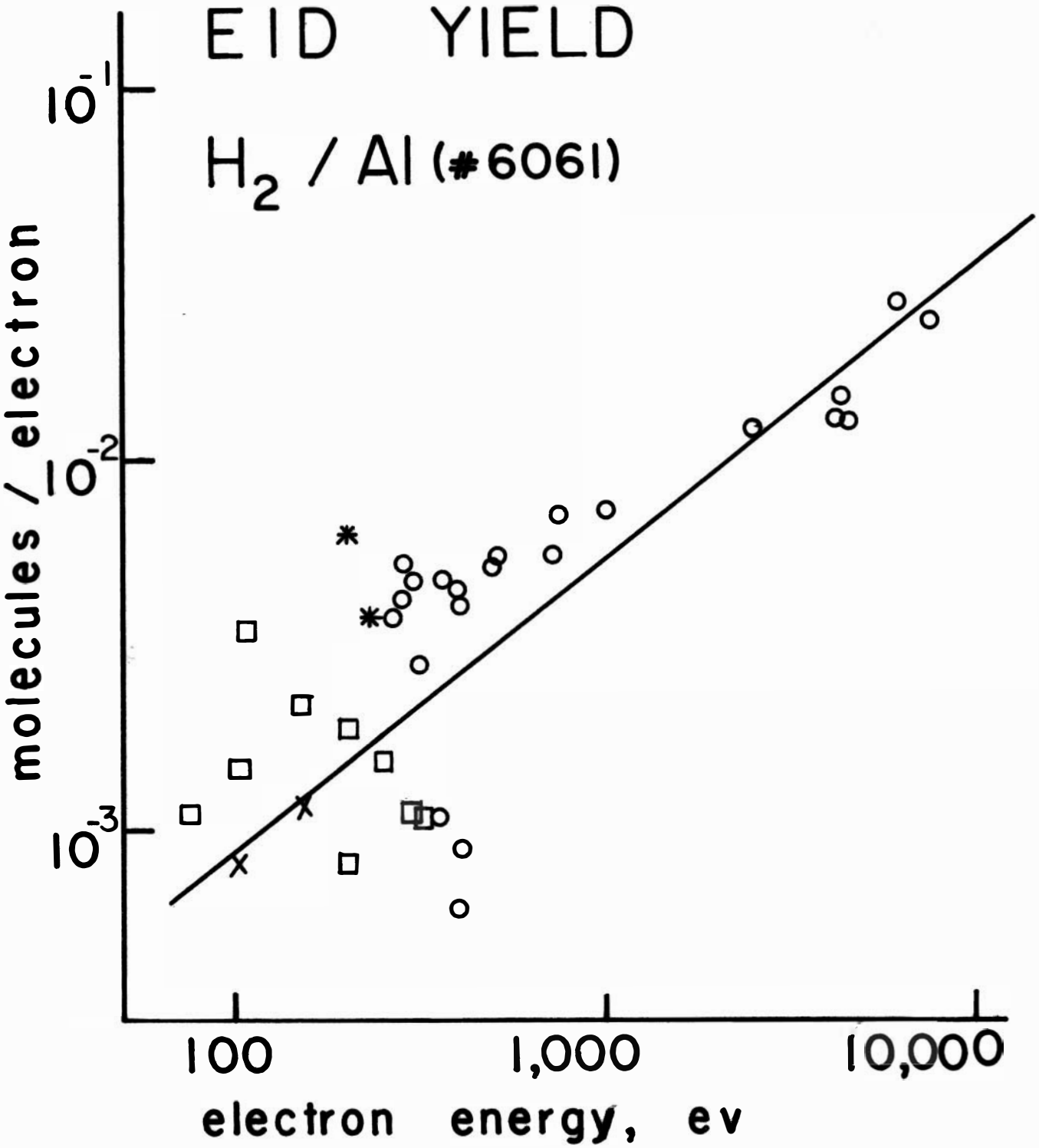

Figure 3. EID yield versus bombarding electron energy for a clean sample of 6061 aluminun, for base pressure $1x10^{-7}$ torr pumped down from air.

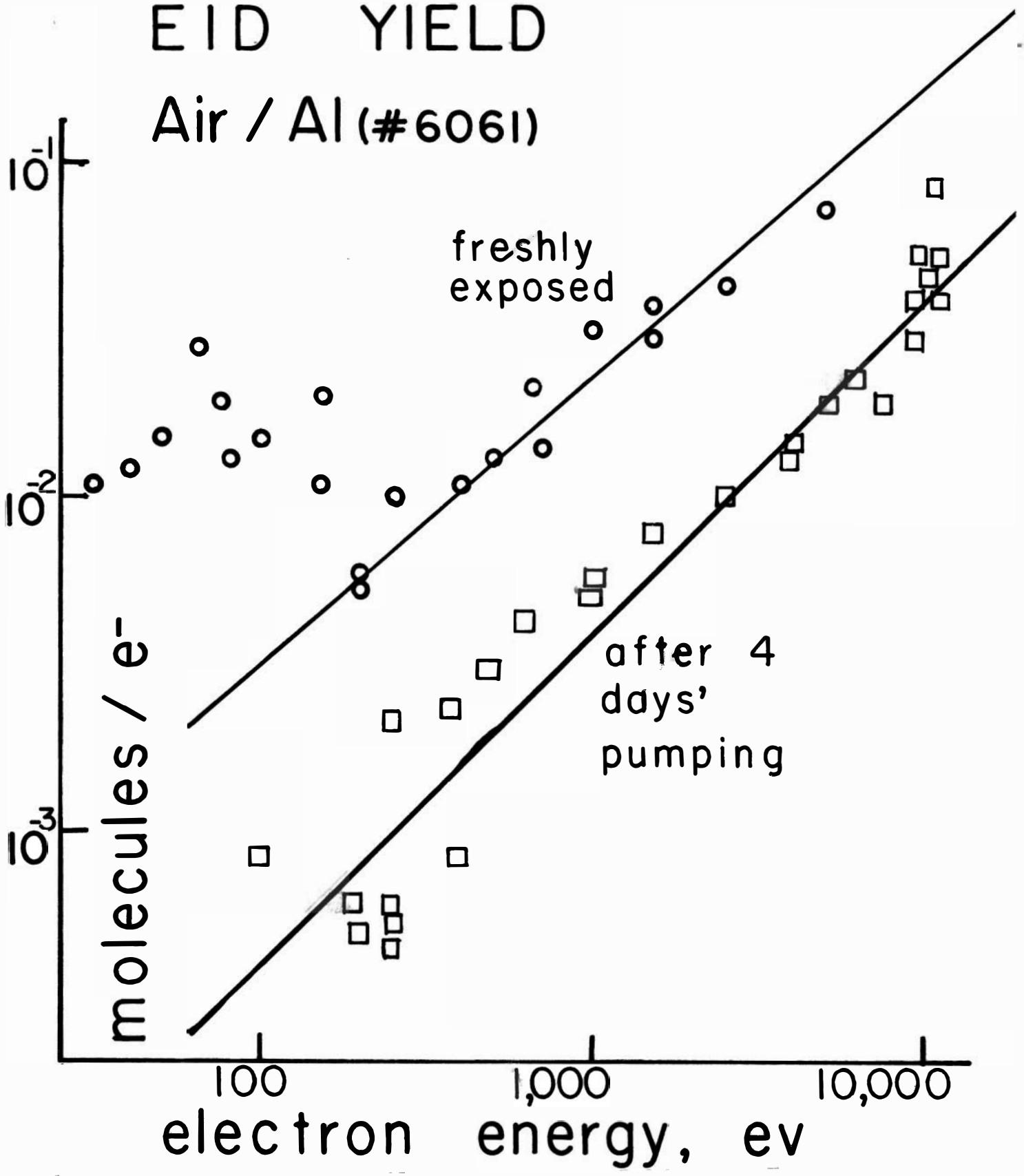

Figure 4. EID yield versus incident electron energy for a sample of 6061 aluminum, for 1×10^{-7} torr base pressure pumped down from over 10^{-5} torr H_2.