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Tandem Notes

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RHIC-PG-23

TANDEM NOTES

1. Heavy Ion Charge States in Foil and Gas Strippers

2. Foil Strippers Lifetimes for Heavy Ions - Possible Problems and Solutions

G. R. Young

(BNL, December 15, 1983)

The purpose of this note is twofold: 1) to provide some graphs allowing estimates of mean heavy ion charge states and fractional stripper yields in the tandem Van de Graaff terminal and at the tandem exit

2) to bring up the question of stripper foil lifetime for heavy beams and thus the question of how long the tandems can operate before a tank opening for changing stripper foils. A tank opening requires depressurizing and later repressurizing the tandem tank with insulating gas and usually requires 1-2 shifts for an MP machine. The foils are in the high voltage terminal; thus the opening requirement.

① The enclosed graphs were run off for our five standard ions, ^{12}C, ^{32}S, ^{63}Cu, ^{127}I and ^{197}Au. The first set is for total energies of 15 - 25 MeV ie the energy of an ion reaching the terminal stripper. The second set is for ~ 100 - 800 MeV total energy, ie the energy at the high energy exit of the machine.

The curves show mean charge state for foil and gas stripping. Foil always yields a distribution which is a) narrower in q b) has a larger mean q than the gas case due to the density effect in stripping. The curves were generated using the program CHARGE written by Royce Sayer of Oak Ridge. Also shown, for a few energies, are the charge state distributions, plotted along the ordinate. These curves were used in calculating the currents presented to the booster injection line in note RHIC-PG- . They agree rather well with the values used by Harvey Wegner using the codes at the BNL tandem.

⟹ see "Noted added", page 8
GRY 12/16/83

(2) The following algorithm for stripper foil lifetime is given by Charles Jones of Oak Ridge. It reproduces quite well the results of a radiation damage code written by Ron Auble of ORNL to calculate stripper lifetimes as a function of Z, A, kinetic energy, current, spot size at the stripper and foil type. The algorithm is

$$\tau\,(\text{minutes}) = K\,\frac{E}{Z^2 M}\,\frac{A}{I} \times 10^6$$, where

E = kinetic energy in MeV of the ion
Z = ion nuclear charge
M = ion mass number
A = beam spot size at stripper in mm^2
I = beam current in particle micro amperes

K = radiation damage constant
= 0.00182 for vapor deposited carbon foils
0.0358 for 6 $\mu g/cm^2$ glow discharge foils

In general, for glow discharge, slackened foils,

$$K = 0.0073\,t\,(\mu g/cm^2) - 0.010$$ for 2-10 $\mu g/cm^2$ glow discharge foils

t = foil thickness in $\mu g/cm^2$

6 $\mu g/cm^2$ is the necessary carbon thickness to bring ^{197}Au at 0.1 MeV/A (ie 15-20 MeV) to its equilibrium charge state as given by the code CHARGE.

In essence the algorithm describes the radiation damage of stripper foils by low energy heavy ions. The damage leads to the foils becoming brittle; the foils finally develop cracks and finally disintegrate and have to be replaced. (The physics is related to that addressed by people worrying about damage to fuel rod casings and other components in fission reactors or fusion reactors.)

The use of foils prepared by hydrogen glow discharge as opposed to vapor deposition of carbon has been found to yield a foil taking more damage to become brittle. (C.D. Galbraith, R Auble et al, ORNL). Physically 'slackening' the foil as it is mounted on its support frame was found by the same authors to further increase lifetime by increasing the tolerance to brittleness. The upgrade for the BNL tandem vandeGraaff included in the AGS transfer line package includes purchasing equipment to make such foils.

One gets the following lifetime table for a 1/8" diameter spot

Ion	τ (minutes-particle μA)
^{12}C	9291
^{32}S	490
^{63}Cu	75.8
^{127}I	11.3
^{197}Au	3.3

This assumed a 15 MV 2 stage machine; 3 stage operation would increase the values of τ by $\frac{24\,MV}{15\,MV} = 1.6$.

Experience at the BNL tandem suggests in pulsed mode the damage done is equal to the equivalent time-averaged beam. At first sight, this looks to be a saving note, as a 200 pμA Au beam injected for 150 μsec each 1.2 seconds (= 1 AGS cycle) for 2 x 57 x 1.2 = 136.8 seconds (57 bunches in each of 2 collider rings) only corresponds to

3.42 pμA - seconds of foil damage, or .057 pμA-min.

Thus one foil should last thru $\frac{3.3}{.057}$ = 57.9 such cycles, or at 1 hour per collider refill, 2.41 days. Then for an 80 foil magazine, 193 days of operation would result before a vandeGraaff tank opening (something else would surely break earlier - Murphy's law.)

However, the tandem requires a quiescent beam be run through it so that it stay steady and "ready to go" when the collider needs a refill (or, rather, the booster needs a pulse). The new pulsed source tends to put out 1 - 2 particle μA quiescent beams, meaning each foil would last ~ 1.6 - 3.3 minutes, or ~~the~~ an 80 foil magazine would be wrecked in 2.2 - 4.4 hours. This is not acceptable.

~~The tandem does have a rotary aperture at the low energy~~ ~~end~~ The tandem has a low energy beam stop - a Faraday cup - which can be ~~injected~~ inserted when the booster does not need a refill. This would avoid destroying foils for no reason. Then ~ 80 collider refills are possible for a 1 pμA quiescent beam. (~ 3 days)

The best thing to do appears to be to reduce the injected quiescent current to 10 - 100 particle nanoamperes. This would increase the foil survival to of the order of 30 - 200 days (at 10 pnA quiescent, the pulsed beam damage takes over.) The beam is put on the low energy beam stop when not used, i.e. for the 55-60 minutes between refills. The beam probably should go back into the tandem a few seconds before it is needed again at the booster so the tandem can settle down from jumping between GVM regulation (beam out of machine) and slit-feedback regulation (beam in machine) of the terminal high voltage.

If it does not prove possible to cut the quiescent output of the source to the 10 - 100 pnA level, then perhaps the Einzel lens at the source could be detuned on a fast timescale (i.e. order of a few μ-sec) to dump (most, but not all of) the beam on a low energy aperture before it reaches the tandem. If this is not possible, a set of fast electrostatic deflectors could be used to deflect the beam to a secondary stop in the injection leg before the low energy tandem tube. This has the disadvantage of taking the beam out of the tandem between pulses while pulsing is going on — the worry is how unstable the machine would be in such a mode, especially if a linac's acceptance must be matched. It would not do well to have the terminal voltage bouncing about.

☆ Probably the tandem staff will come up with more clever solutions to this problem. It is important to make foil lifetime tests for pulsed gold beam on a rather quick timescale.

If we cannot persuade the foils to last, a fallback position does exist. One can use gas stripping in the tandem terminal for the heavy beams (i.e. Au and I.) This has the disadvantage of much lower charge states and energies. We work out the implications below – the final energy for gold out of the booster ring is of especial concern here, as we must be fully stripped in the AGS due to the moderate AGS vacuum (10^{-7} torr).

Terminal Gas stripping   15 MV 2 stage tandem

Ion	@ 15 MeV $\langle q \rangle_{gas}$	E_f (MeV)	@ E_f $\langle q \rangle_{foil}$	$B\rho = 16.6$ T·m $E_{booster}$ (MeV/A)	β at tandem exit
^{12}C	5^+	90	6^+	1727	.1261
^{32}S	7^+	120	14^+	1438	.0895
^{63}Cu	7^+	120	20^+	903	.0639
^{127}I	6^+	105	25^+	421	.0421
^{197}Au	5^+	90	28^+	238	.0313

We still used foil stripping at the high energy end, as this stripper is easily accessed. The booster energy is based on the foil charge state $\langle q \rangle_{foil}$. The table below gives the results for 3 stage operation (−9 MV on MP6, +15 MV on MP7 – this gives a foil lifetime of 5.3 minutes, still not enough.)

Ion	@ 24 MeV $\langle q \rangle_{gas}$	E_f (MeV)	@ E_f $\langle q \rangle_{foil}$	$B\rho = 16.6$ T·m $E_{booster}$ (MeV/A)	β at tandem exit
^{12}C	5^+	99	6^+	1727	.1322
^{32}S	8^+	144	~~14^+~~ 15^+	1582	.0979
^{63}Cu	9^+	159	22^+	1041	.0735
^{127}I	8^+	144	29^+	538	.0493
^{197}Au	6^+	114	31^+	286	.0352

These energies are OK for stripping C, S, Cu and I but will give relatively poor yield for Au (a guess is 20 - 40%). Of course, the catch is that foil lifetimes are long enough for C, S and Cu that we don't need to worry about breakage. "The foils give trouble just where you need them most" (quote from any frustrated tandem operator)

For reasons of reliability, 2 stage tandem operation is preferred. Both could be kept equipped with dual sources for different mass operation in the collider. One could be down for repairs or foil changing without jeopardizing collider operation. As the 2 stage numbers give more trouble with stripping efficiency at the booster exit, we could consider the following:

1) Run gas stripping in the tandem terminal if we cannot get foils to survive long enough
2) Do not foil strip at the tandem exit – instead, add a few low β cavities of Heidelberg design which can also handle low q. These cavities bring the energy to 1.4 MeV/A (Gold)
3) At a position just after these cavities, insert a foil stripper mechanism. This gives, at 1.4 MeV/A, Au^{40+}.
4) Complete the rest of the linac, inject into the booster
5) Energy at booster exit, $B\rho = 16.6$ Tm, Au^{40+}, is 443 MeV/A. This should strip to Au^{79+} at markedly better than 50% efficiency.

Note Added 12/16/83

After discussing the foil lifetimes with H Wegner, he suggested it may be possible to rearrange the high voltage distribution in the source to yield a quiescent beam near 0 μA, certainly ≲ 1 p nano-amp.

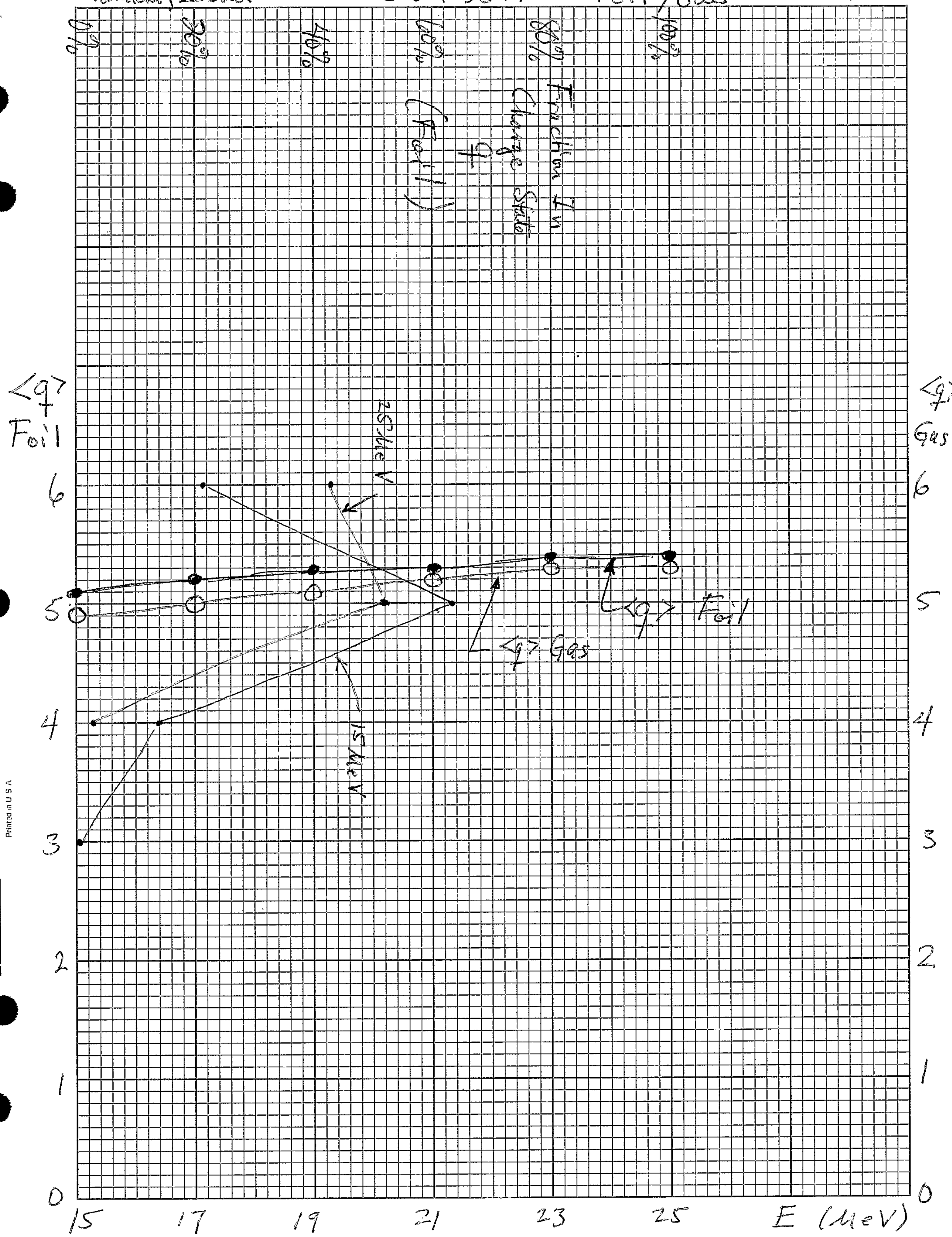
Then, the foils would last months, if our algorithm is correct, before a tank opening to load a new foil magazine would be needed.

He plans to make foil lifetime measurements, for 2-stage and 3-stage beams, as soon as possible, especially for iodine and gold.

Taking the beam in and out of the machine like this requires using GVM regulation, which is steady but not as steady as slit regulation. How this affects stability, energy spread and the emittance ellipses vis à vis injection into the linac and/or the booster or AGS will be studied in the near future.

Bottom line – "problem" may evaporate, but we need some measurements to determine if it will.

Tandem, LEend ^{12}Carbon - Foil/Gas 12/11/83

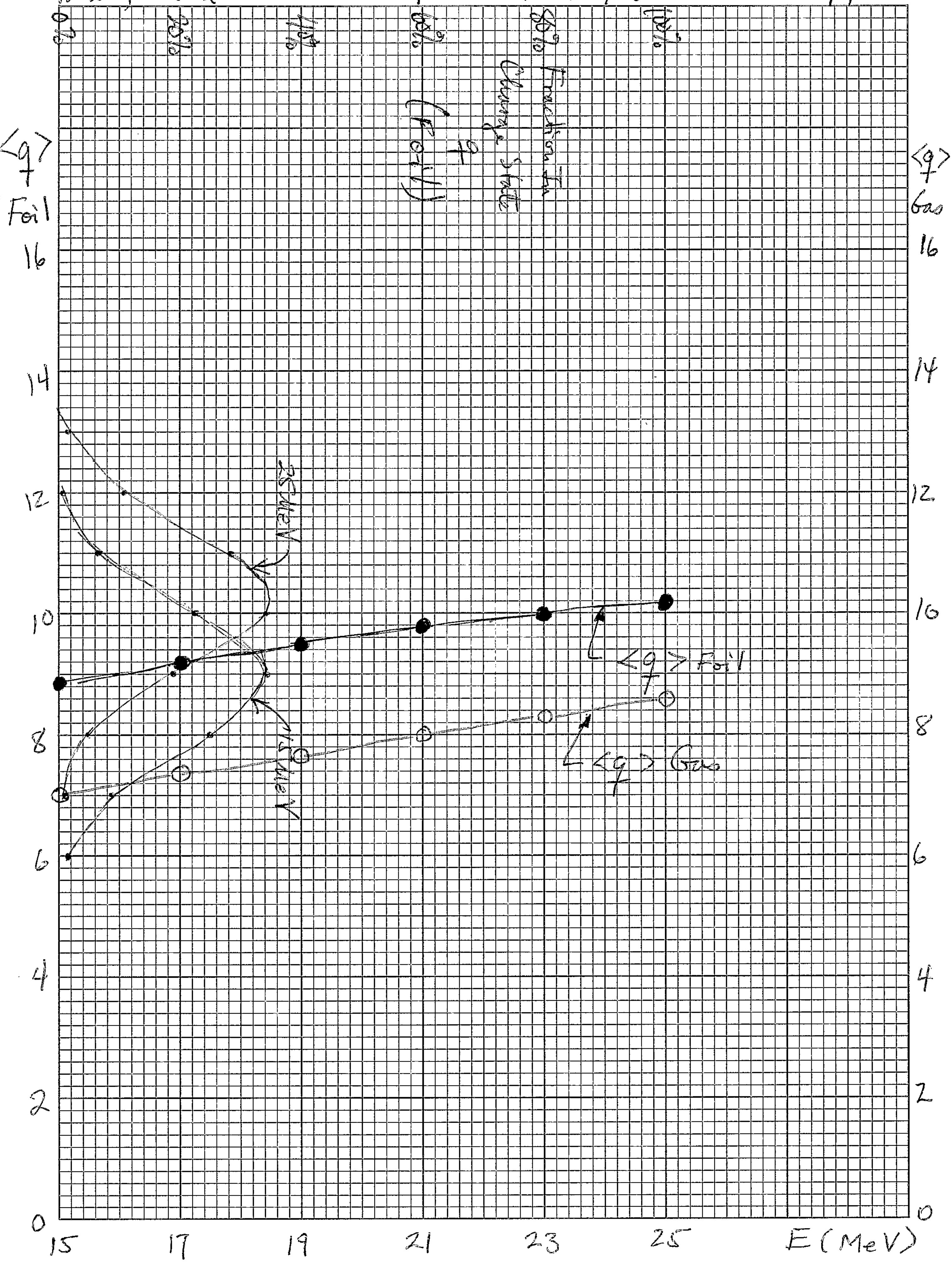


SQUARE 10 X 10 TO THE INCH AS-0807-GO
GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo, New York
Printed in U S A

Tandem, LE end

^{32}Sulfur - Foil/Gas

12/11/83



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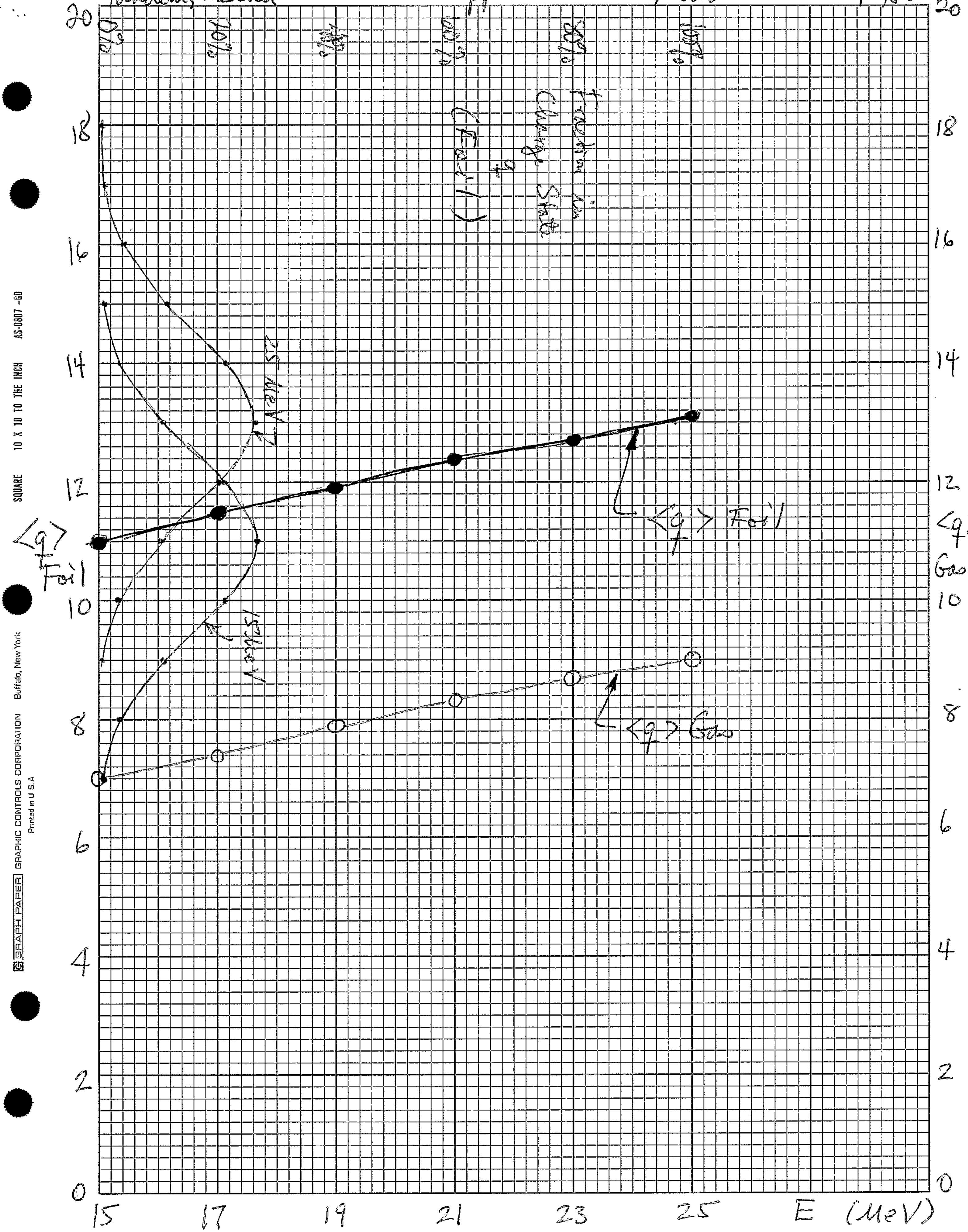
Tandem, LE end — ^{63}Copper – Foil / Gas — 12/11/83



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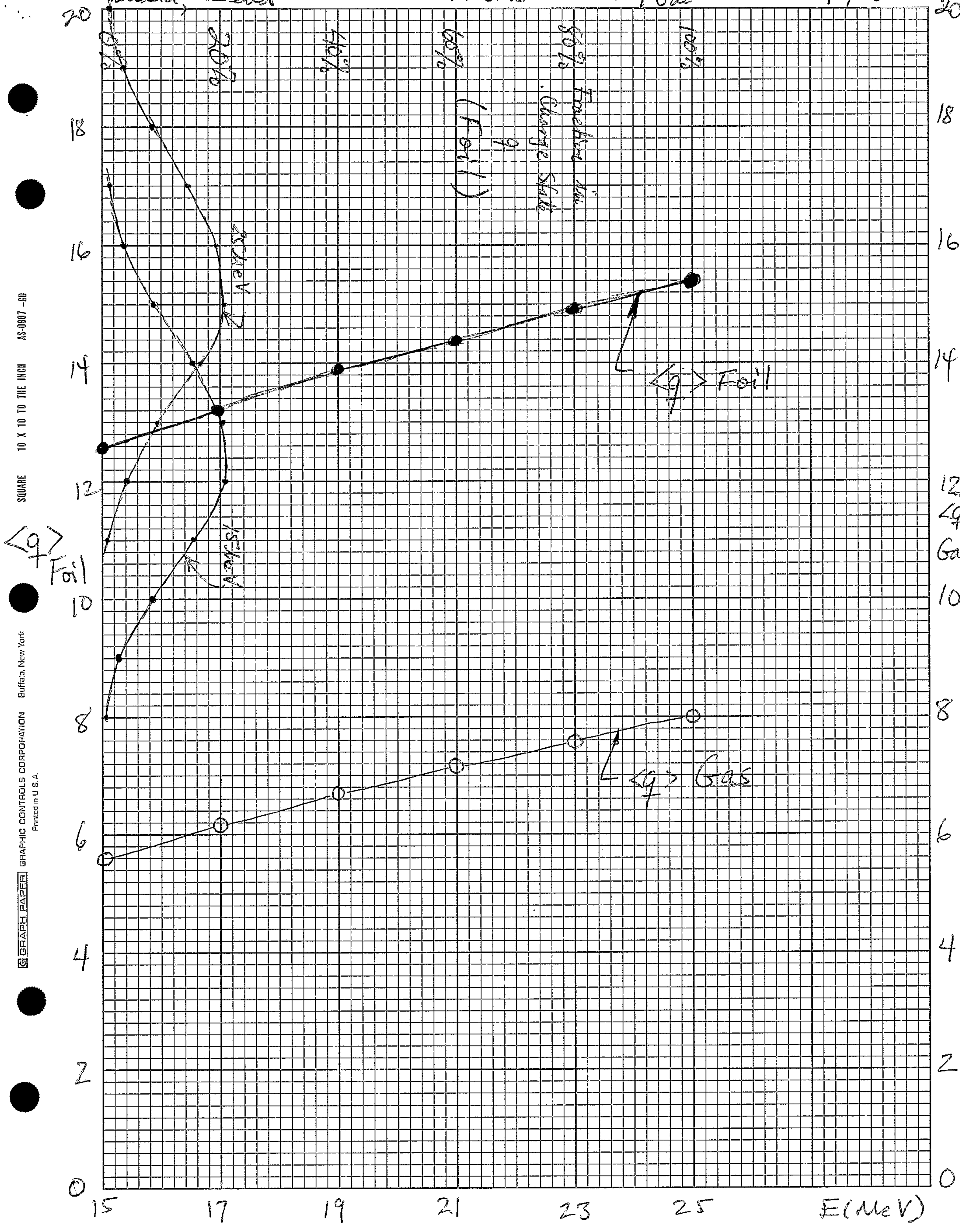
Tandem LE end — ^{127}Iodine - Foil/Gas — 12/11/83



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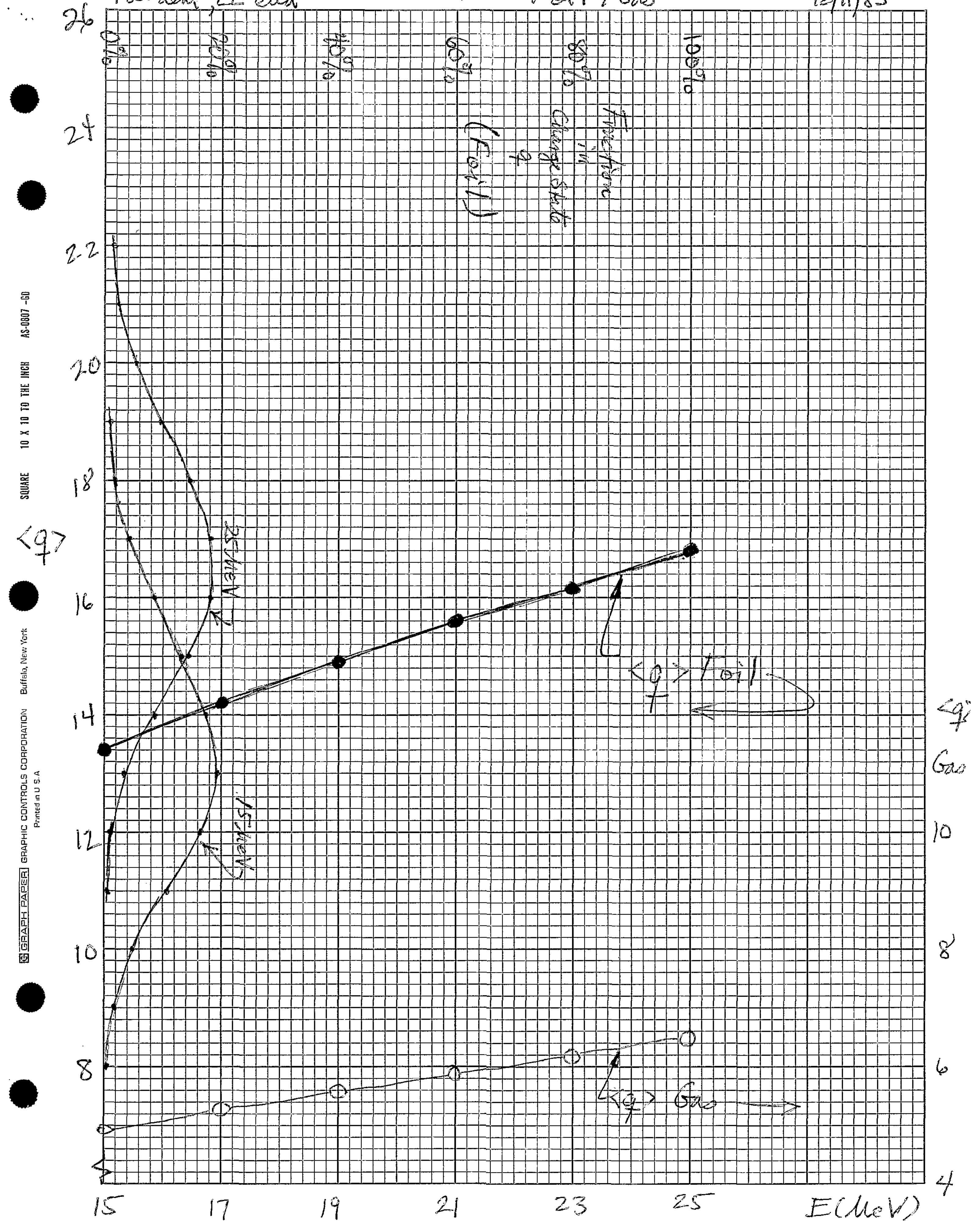
Tandem, LE end 197Au - Foil / Gas 12/11/83



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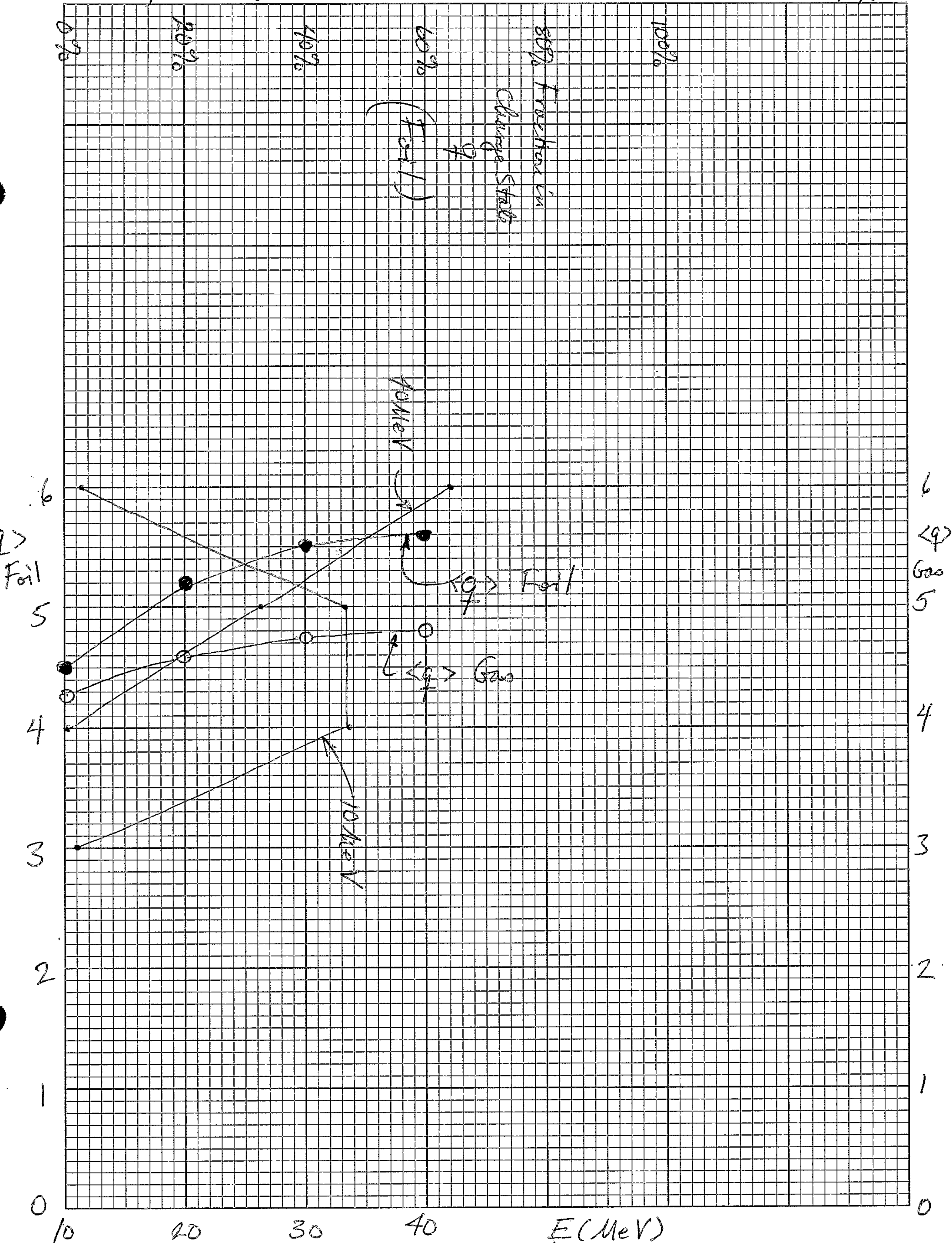
Tandem, HE end

^{12}Carbon - Foil / Gas

12/11/83



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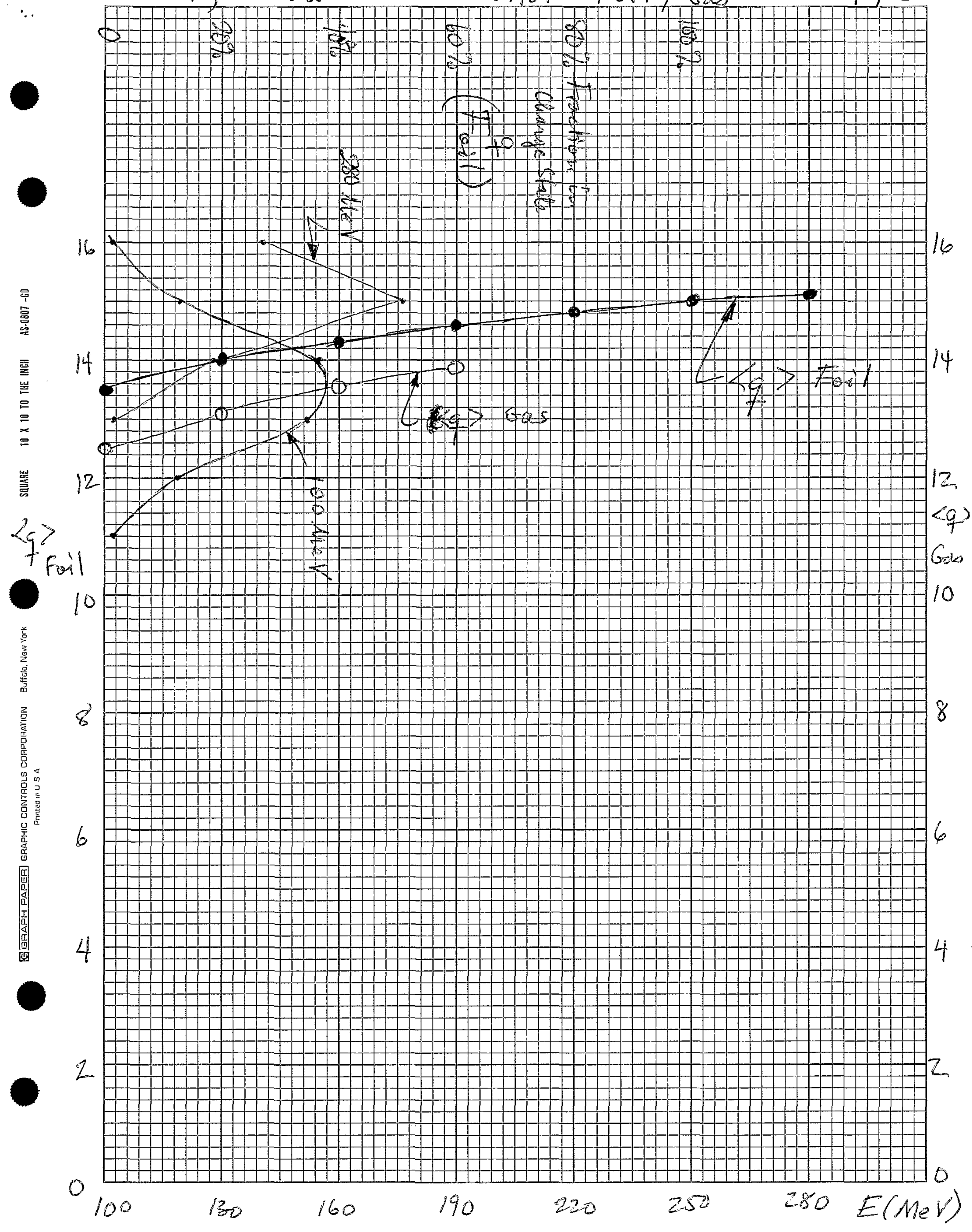
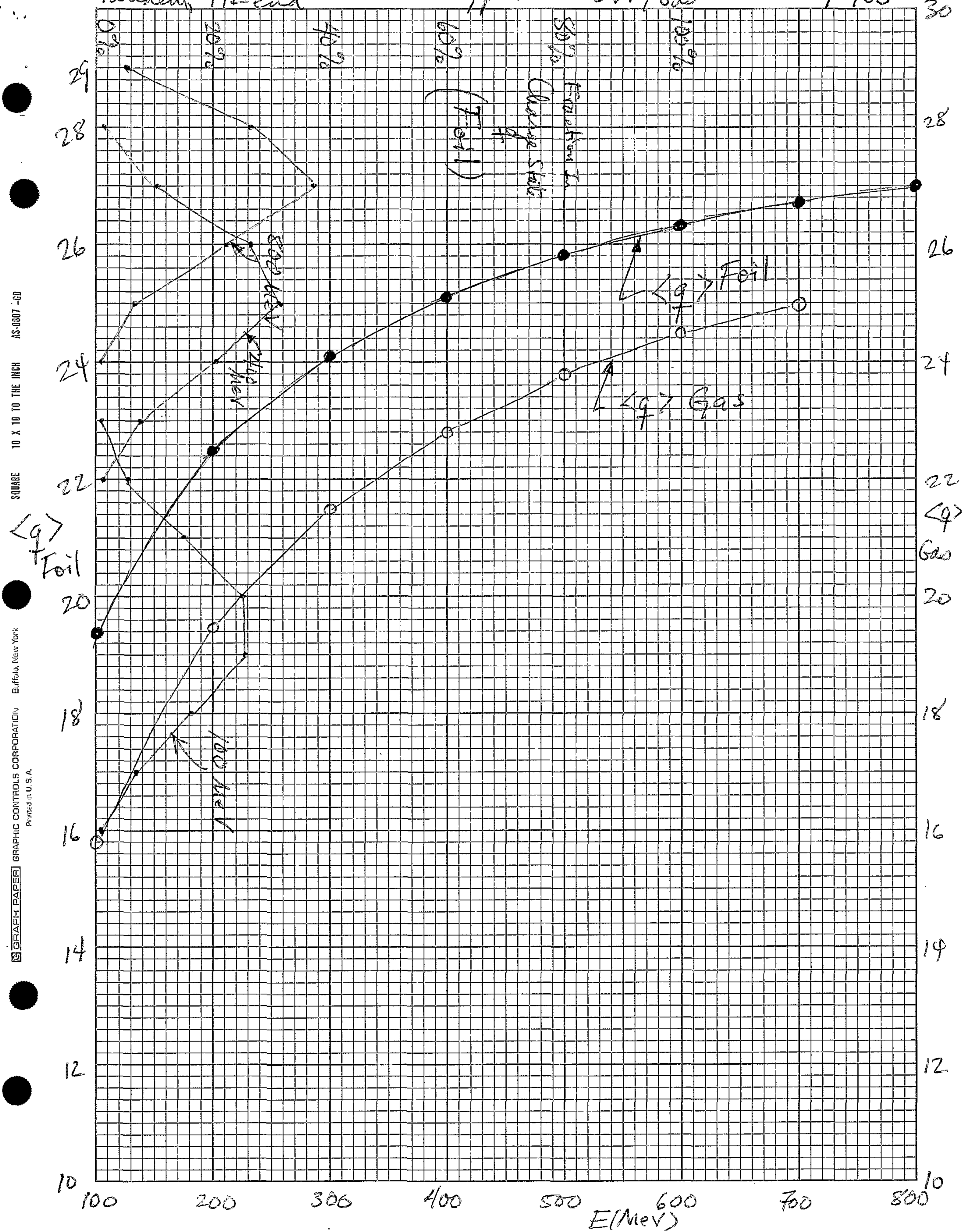
Tandem, HE end ^{32}Sulfur – Foil / Gas   12/11/83



Tandem, HE end ^{63} Copper - Foil/Gas 12/11/83



SQUARE 10 X 10 TO THE INCH AS-0807 -GD
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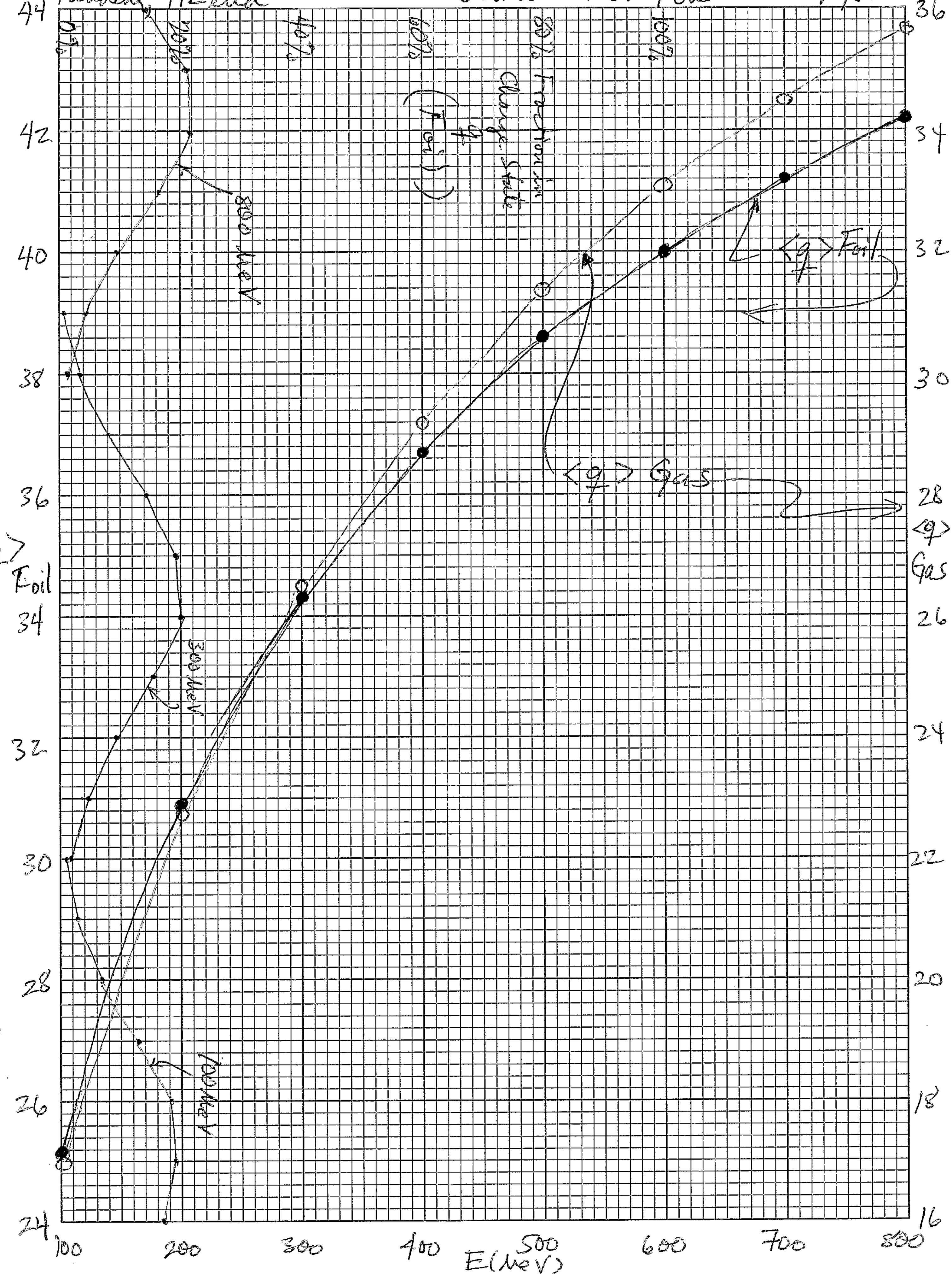
Tandem, HE end   127 Iodine – Foil/Gas   12/11/83



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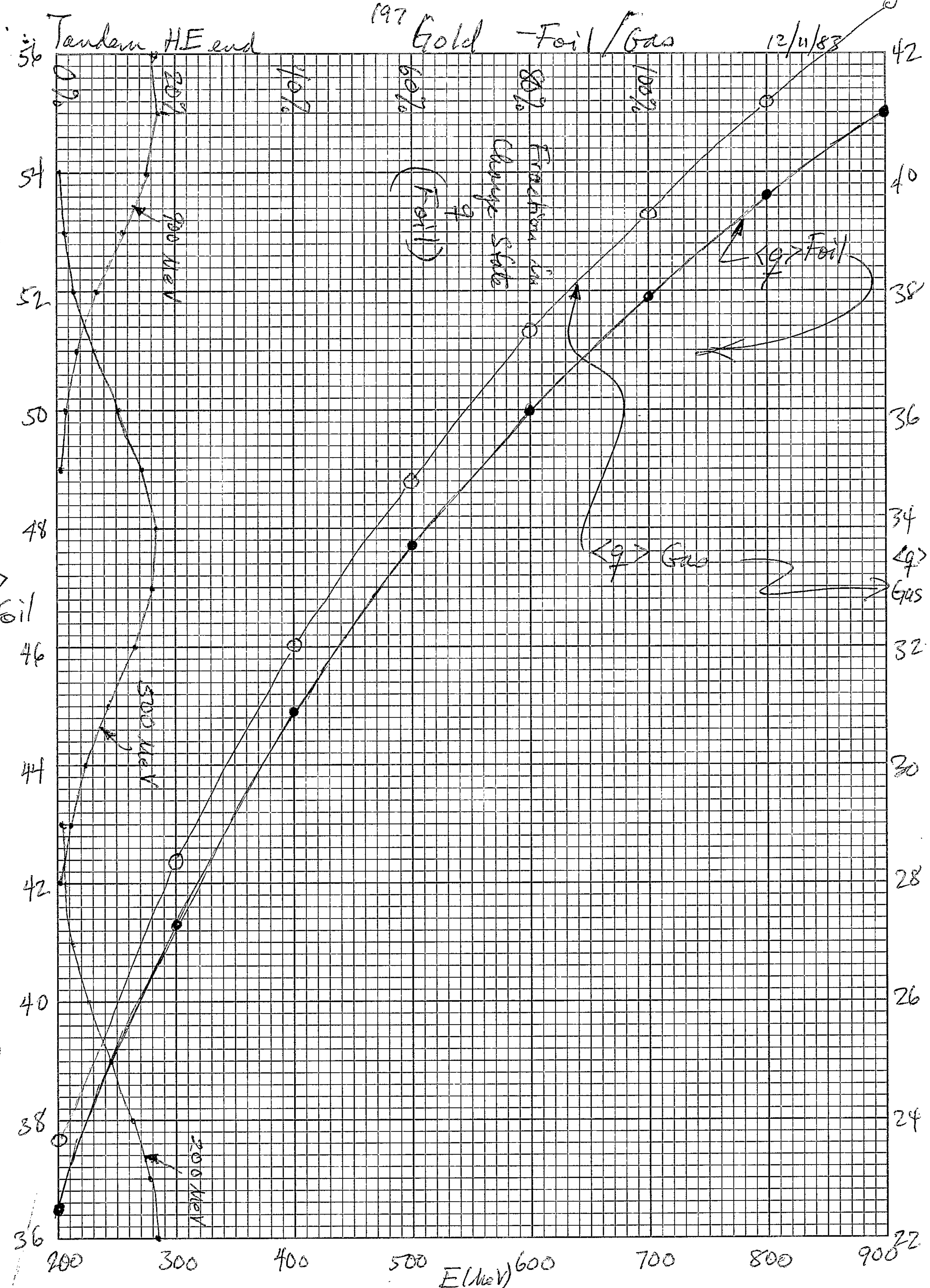
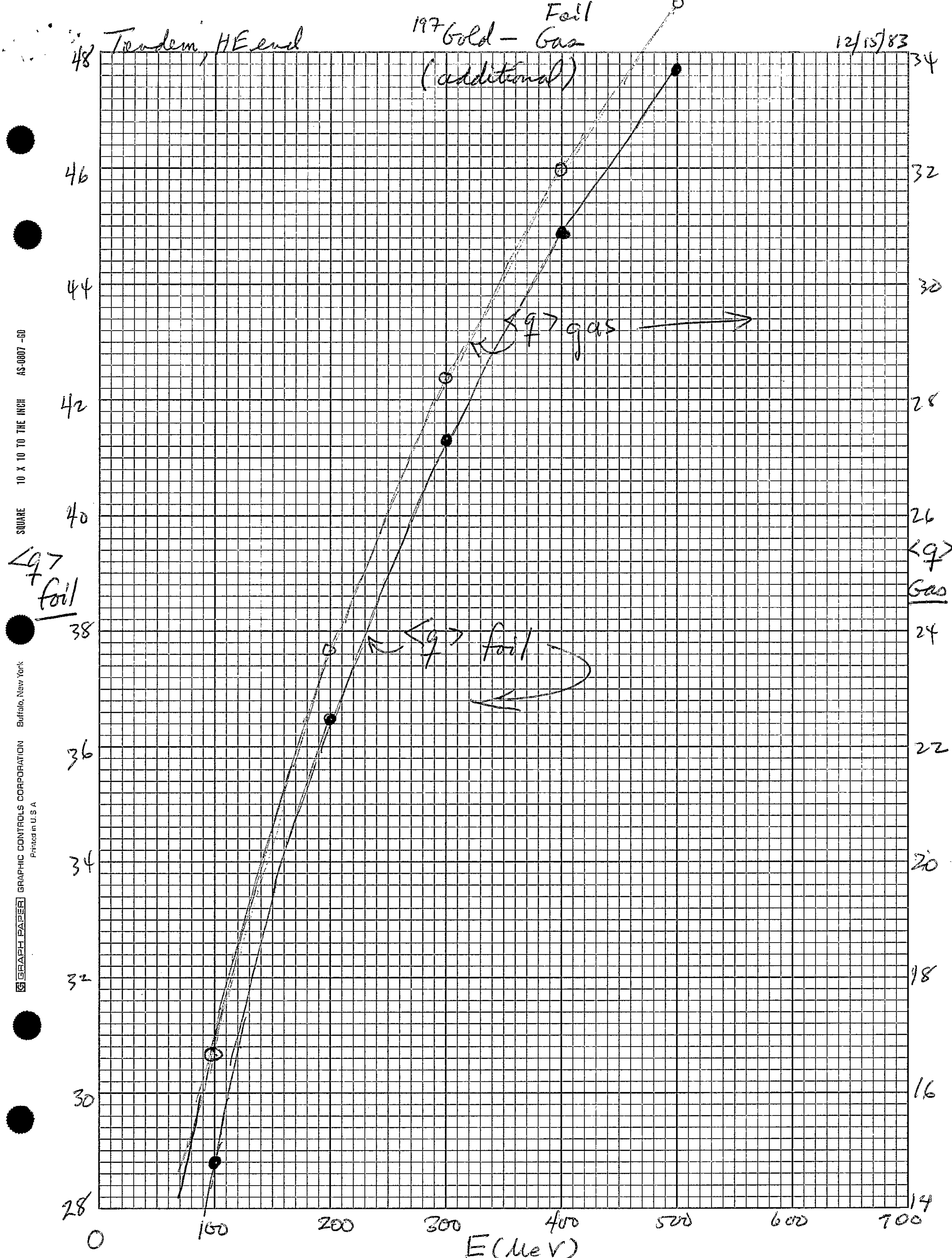


Tandem HE end
197 Gold Foil/Gas
12/1/83
Fraction in Charge State
q_f (Foil)
0%
20%
40%
60%
80%
100%
900 MeV
500 MeV
200 MeV
⟨q⟩ Foil
⟨q⟩ Gas
E(MeV)
GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo, New York Printed in U.S.A. SQUARE 10 X 10 TO THE INCH AS-0807-GD



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