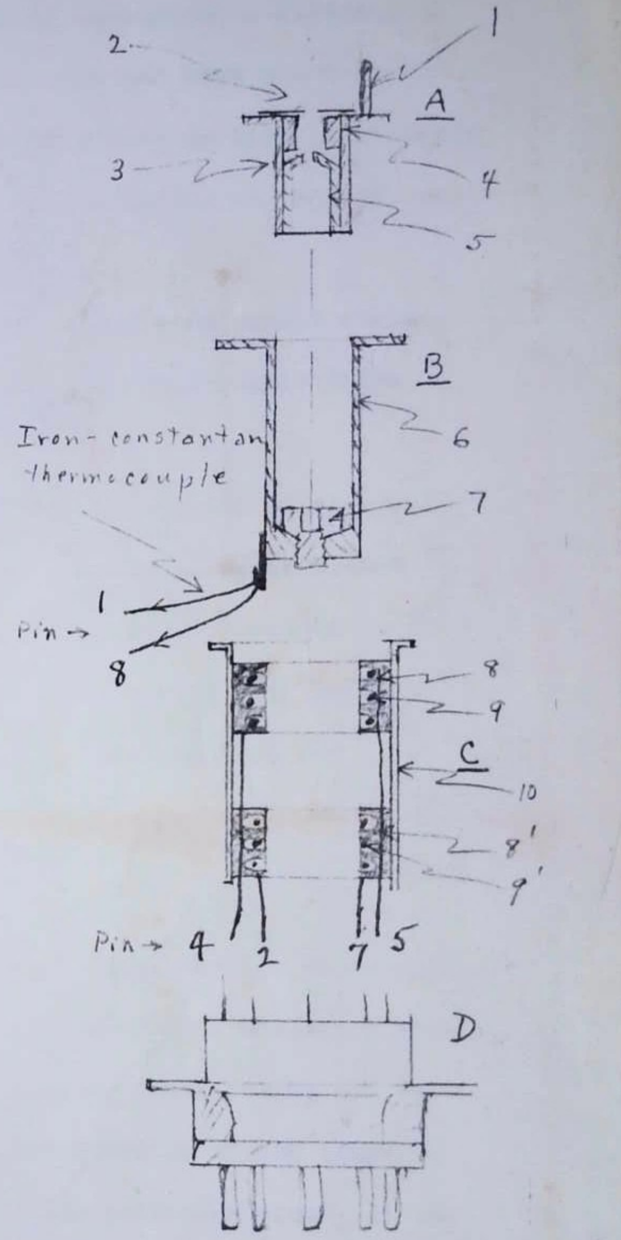
DESCRIPTION OF STERN-GERLACH APPARATUS

I. <u>The Potassium Source</u>

The oven consists of the three parts shown: A, B, C. All are made of stainless steel.

The thin-walled cylinder 10 of part C is spot-welded by means of three legs to the octal base header, D. These legs are the main support of the structure. Inside C are two coiled tungsten wire heaters, 9 and 9', contained in interior-grooved lavite pieces 8 and 8'. In practice only the top heater is used. Connections to the two heaters come out at the numbered octal pins shown in C.

The potassium pellet is placed in cylinder B. In the original assembly, part B was wrapped with thin mica, inserted into C and the edges of the flanges were then spot-welded together. The No. 6 stainless steel screw 7, in the bottom of B serves two purposes. If removed, a bright light can be directed at the sealed-off glass tubulation in the



Pin

1 Thermocouple	5 Upper Heater
2 Lower Heater	6 —
3 —	7 Lower Heater
4 Upper Heater	8 Thermocouple.

Figure 1

base or header and, when the whole apparatus is assembled, a diffraction pattern can be seen between the curved pole pieces and thus the location of the slits may be adjusted to insure that the potassium beam is properly directed. The other function of the screw is in cleaning the unused potassium out of the oven.

The iron-constantan thermocouple is spotwelded to a nickel strip which in turn is spotwelded to the base of B. The thermocouple leads go to pins 1 and 8.

Slit holder A contains two slits. The one on the end of sleeve 5 is about 0.3 mm wide. Slit 2 is made of stainless steel razor blades and is about 0.03 mm wide. The two pieces of the fine slit jaws are spotwelded to A. Pin 1 on A guides the oven into a position such that this slit becomes parallel to the slit located at the entrance of the beam into the magnetic field.

II. The Detector

When neutral potassium atoms strike a hot tungsten wire an electron is stolen and the positively charged potassium ion may be collected with an electric field. The ratio of those striking to those coming off is given by exp $[-(\psi - \varphi)/kT]$, where ψ is the work function of the tungsten surface and φ is the ionization potential of the potassium atom. It is desirable that this ratio be very nearly unity or the potassium atoms will build up on the tungsten and increase the background. Thus, $kT \gg (\psi - \varphi)$. For the tungsten wire here used, its temperature must be higher than about $1600^{\circ}K$ if the background is not to build up.

The ionized potassium atoms are collected by a metal cylinder that surrounds the hot tungsten wire. This cylinder in turn is fastened to the grid lead of an electrometer tube. The tube is contained in the vacuum and thus no high impedance leads are brought outside. The tube has a 10^{12} ohm resistance in its grid lead*.

The mechanical arrangement, including the method used for allowing mechanical motion of a micrometer screw through a vacuum wall, is shown in Fig. 2. The electrometer tube and $10^{12}\Omega$ resistor are mounted in a lavite insulator. This lavite piece is mounted on 4 springy metal-strip legs that are fastened to the actual base. A ball in the lavite gives a thrust bearing for the end of the micrometer screw. Note the two "O" rings used for the vacuum seal. The fore-vacuum pump evacuates the space between the rings. Thus the pressure across the ring nearer the much better vacuum is perhaps 10^{-3} mm of Hg instead of $\sim 10^{3}$ mm as would be the case with one ring.

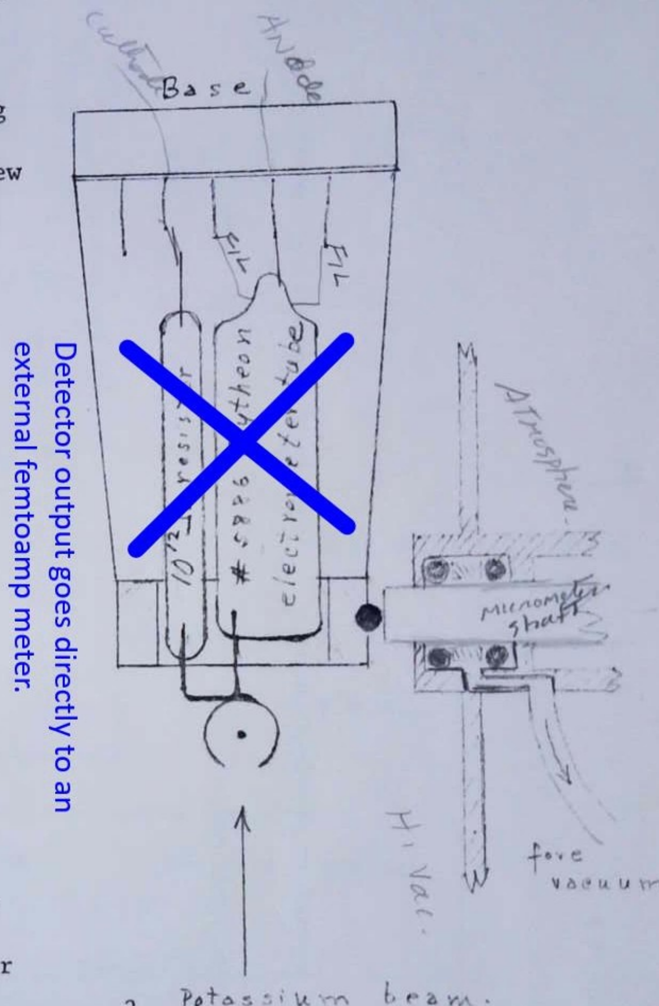
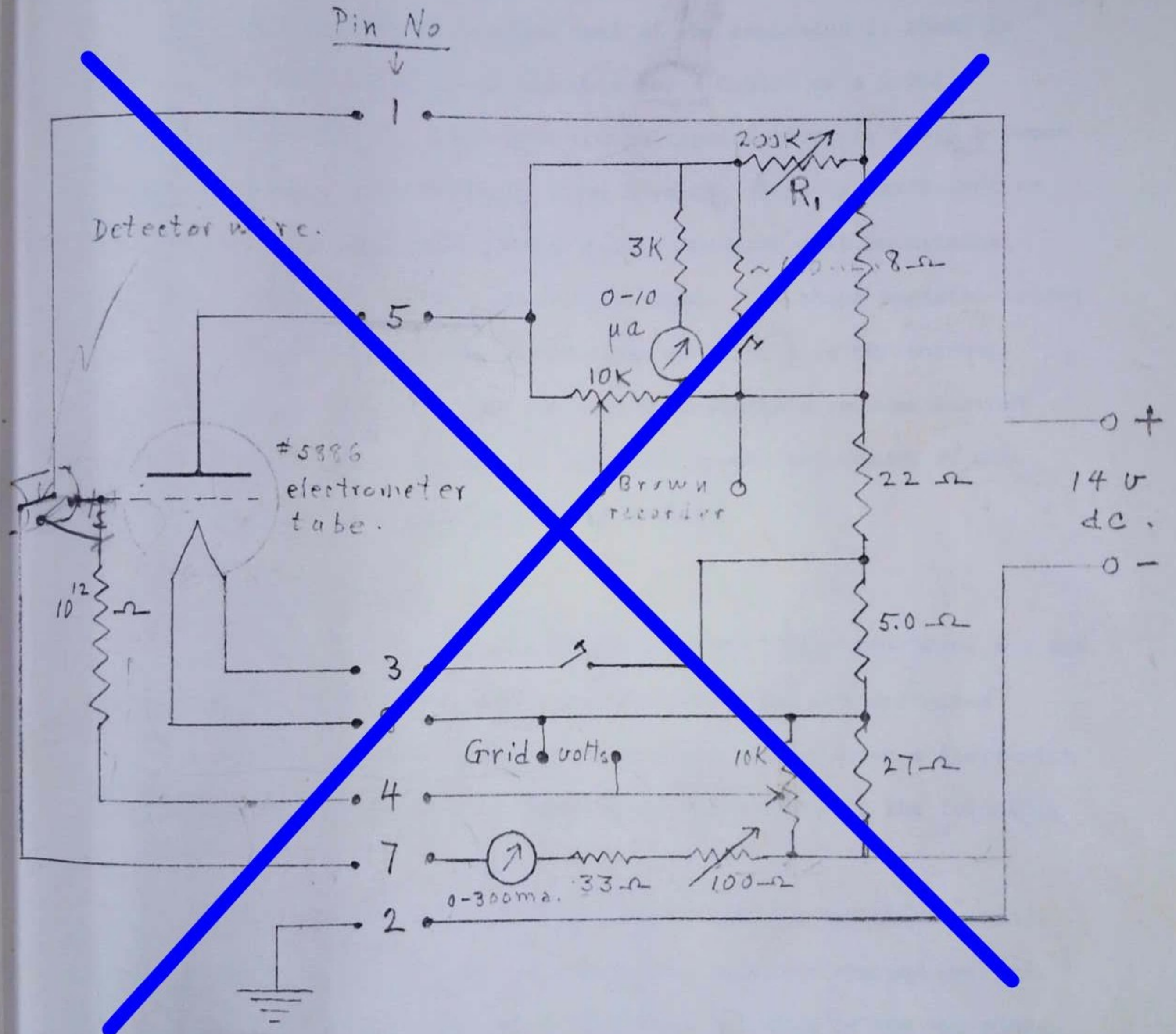


Figure 2

* An electrometer tube may have a very large current gain. The Raytheon No. 5886 tubes here used vary considerably from one to another. It is not too difficult, however, to find one which will give a change of plate current of 1 microampere for a change of 10^{-13} amperes into the grid with a 10^{12} ohm grid resistance. This is a current gain of 10^{7}.



Schematic diagram of detector part of Stern-Gerlach Apparatus. The 14v is obtained from a laboratory d.c. power supply. Note: Do not exceed 14v.

Figure 3

In addition the part of the micrometer that passes through these rings is very smooth. The net result is very little leakage as the screw is turned.

The circuit for the detector part of the apparatus is shown in Fig. 3. The 0-300 ma meter is suitable for a 0.001" or a 0.002" tungsten detector wire. Note that the collecting electric field between wire and cylinder is produced by about 6 volts. This is sufficient to cause saturation. The grid voltage may be measured with an external voltmeter. A Brown recorder may also be used. The shunt resistor across the meter is adjusted to give a reduction of 10 to 1 in the current sensitivity of the meter. The resistor R_1 produces a reverse current through the 0-10 microammeter, so that with proper adjustment of the grid-voltage control, the meter may be zeroed.

III. The Magnetic Field

The potassium atoms have a magnetic dipole moment and hence are not deflected in a uniform transverse magnetic field but are deflected in a transverse magnetic field with a gradient. To produce a field with a gradient that is amenable to calculation one can employ the following geometry.

Consider the electric field and equipotentials due to two small, long, parallel wires with equal but opposite electric charges per unit length. If the wires extend in the z-direction, then in the x-y plane, the equipotentials are circles with centers along the y-axis as shown in Fig. 4(a), while the orthogonal lines of force are also circles with centers along the x-axis.

Consider two lines of force of the above system, a and b of Fig. 4(a).

Suppose these were made of a thin conductor, extended in the z-direction, and were maintained at a difference of potential, V. (They could not, of course be connected where they come together at the wires of the previous problem). Then the lines of force due to this arrangement would be identical with the equipotentials of the case for fine wires discussed above.

Now let one iron pole piece of an electromagnet have the shape of b of Fig. 4(a) while the other pole piece has the shape of a. Then the lines of magnetic induction B would be identical to the lines of force discussed above. (Except for edge effects.) The potassium beam is directed through this magnetic field as shown in cross-section at c in Fig. 4(b).

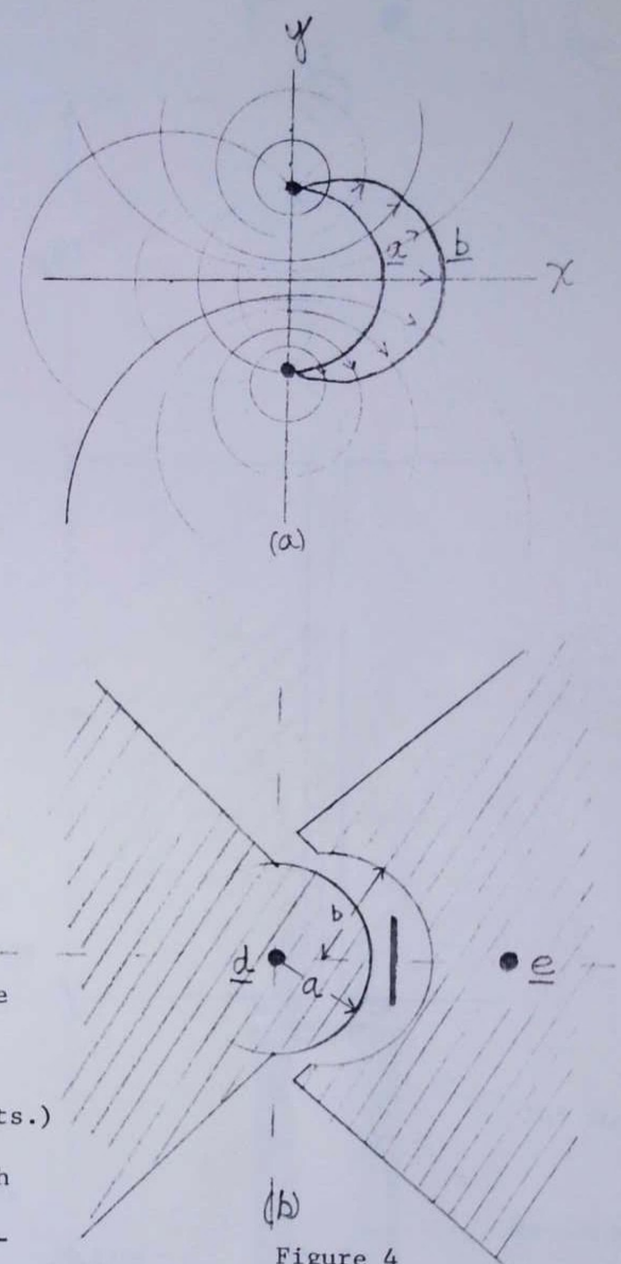


Figure 4

In the present apparatus, the beam is approximately at z = 1.2 a from the center of the cylinder of radius a. Also, a = 0.56 cm and the radius of b = 0.63 cm. For these dimensions, it can be shown that*

$$\frac{1}{B}\frac{\partial B}{\partial z} = - \frac{0.98}{a} = - 1.8 \text{ cm}^{-1}$$

* See "Molecular Beams", Ramsey, p. 432, Oxford Press, 1956.

IV. The Geometry of the Apparatus

In Fig. 5 the relationships of the essential parts of the apparatus are shown approximately to scale. Because of the fact that the beam must be guided accurately through the magnetic field, it is essential that provision be made to assure not only that the geometry is correct, but also that it remains correct when the apparatus is taken apart and re-assembled.

To assure that slit No. 3 always be properly positioned, two long pins, a a', Fig. 5, mounted in the pole pieces (shown also at d and e of Fig. 4) guide the end of tube b, Fig. 5, when it is inserted into the source end of the 2" dia. stainless steel tube that forms the vacuum wall. Tube b (1" dia.) also contains a hardened lavite ring which accepts the slit end of the oven. The pin on the slit end of the oven (see 1 of Fig. 1) goes into a hole in this ring when the oven is inserted. If slits 3 and 2 have been accurately aligned previously

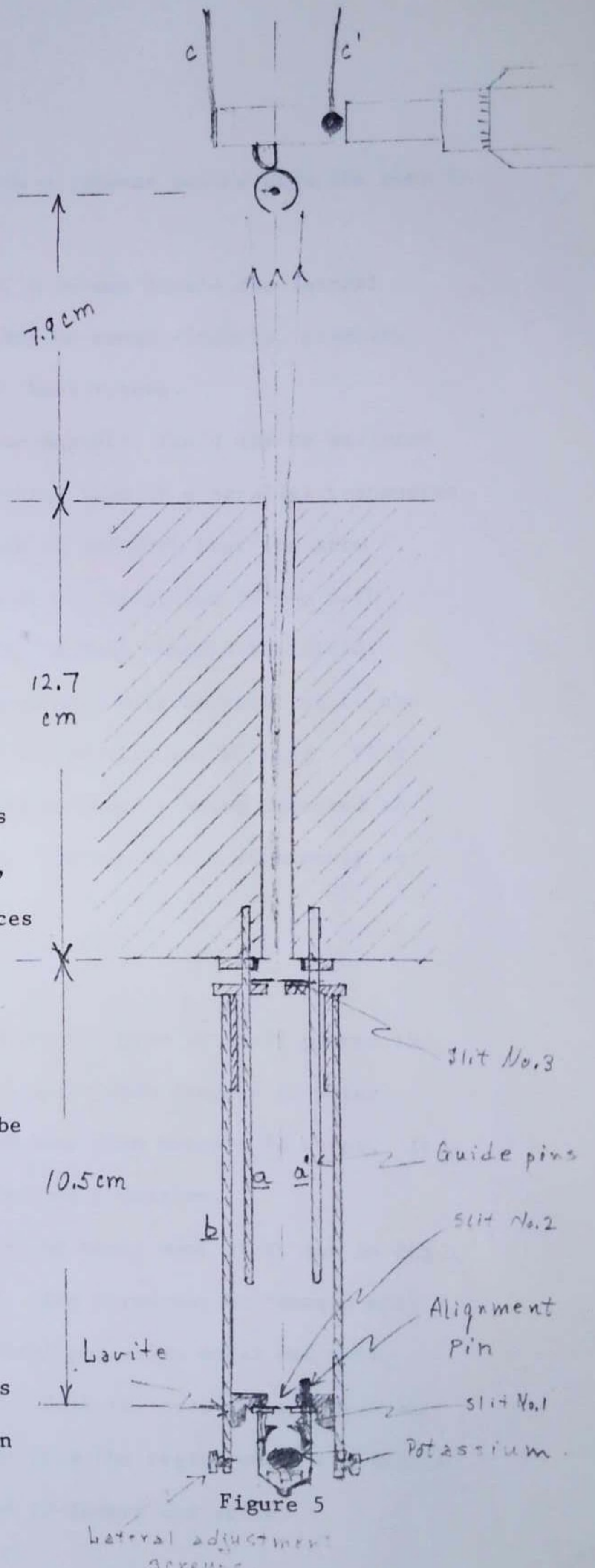


Figure 5

this pin will accurately assure that re-alignment occurs when the oven is re-inserted.

At the lower end of the 1" tube, 4 screws locate the lateral position of this end. The beam may thus be moved slightly, pivoting around slit No. 3 by adjusting two of these screws.

The deflection of the beam in the magnetic field may be analyzed similarly to the deflection of an electron beam in a parallel transverse electric field. The backward extension of the path that the atom takes after leaving the field intersects the extension of the path before it enters the field at the point halfway through the field.

It is also important that the detecting wire be parallel to the slits. The octal base and header are sealed with an "O" ring. This may be rotated slightly when the potassium beam is being detected to obtain a maximum reading of the meter. (Do not handle vigorously so as to destroy the vacuum.)

V. To Load the Oven

Note: Be careful with potassium metal. Even in small pieces the hydrogen generated will spontaneously ignite when dropped in water. Pieces of a few mm^3 in volume, will explode when dropped in water. It is best to protect one's eyes when handling potassium.

1. If there is potassium left over in the oven, most of it may be dug out with a knife or proper size drill. The screw may be removed with a proper size Allen wrench. Wash the final potassium metal out with distilled water and then with alcohol. Hold the oven upright when so doing so that these liquids do not get into the region where the heater is located. Dry the oven with air and re-insert the screw.

2. Potassium metal comes in lump form, immersed in mineral oil. Place a lump on a piece of metal or glass and cut a piece about 3 mm x 3 mm x 3 mm with a razor blade. With tweezers, dunk the piece in xylene, then insert in the oven. Replace the slit system, but insert only about 2/3 rds the way in. This is to allow room for the pin in the slit system to seat properly in the hole in the lavite when the oven is inserted.

3. To insert the oven rotate the apparatus between the pole pieces of the electromagnet until the lower end is clear of the iron forming the lower part of the magnet. It may be held in this position by tightening the adjusting screw of the magnet pole gap. Insert the oven and rotate until the pin finds the hole. Then push upward until the "O" ring seats properly. The slit assembly will thus be pushed down into the oven. Evacuate the apparatus.

Note: It is important that a minimum of time elapses between the cutting of the potassium pellet and the evacuation of the apparatus. Exposure of the potassium surface to air causes a membrane to form. To get a beam started, the thicker this membrane the hotter the potassium must be heated. Even a minute to cut, wash in xylene, place in oven, insert oven and evacuate, is sufficient to build up a coating such that the oven temperature must be raised to 150^{o}C to start a beam. Once started, the temperature is then dropped down to about 110^{o}C.

VI. Some Characteristics of the Oven

1. Using the top heater the slits are kept hotter than the potassium. This is important, to keep condensation of the vapor from occurring at the slits, resulting in clogging.

2. There is a time lag between power being applied to the heater and the change of temperature of the potassium or of the thermocouple. This amounts to a minute or so. As a result, when power is applied and the temperature rises, the temperature of thethermocouple will overshoot although the power is turned off when the meter needle comes opposite the red-needle setting. The hunting dies out after a few oscillations, or after a lapse of 5 or 10 minutes.

3. The thermocouple meter uses a light sensitive diode. When the thermocouple needle is below the red needle, the resistance of the diode is about 5000 ohms. When above the red needle, the diode resistance is about 400,000 ohms. The transition takes place smoothly but within a narrow range of movement when the needles nearly coincide. The light from a small lamp inside the meter, shining on a half black - half reflecting vane on the pointer, causes the diode resistance to change. A transistor circuit takes this input and is amplified to control the power to the heater in the oven.

4. If the power to the oven is turned off (say, by moving the red pointed to the left of the other pointer) the temperature of the oven drops at about 3^{o} per minute at 100^{o}C.

5. The thermocouple has no fixed reference temperature. The meter is set to read 25^{o}C which is close to ordinary room temperature. If room temperature differs from this there will be a corresponding error in the temperature of the oven.

6. A charge of 0.03 cm^{3} of potassium will last for many days. One run with such a pellet was for 384 hours with a suitable beam. On opening the oven a considerable amount of potassium was left. Also, no evidence of potassium was found in the apparatus. Evidently the rate of

A different scheme and circuit is used for the over temperature control nowadays. The temperature control should be nice and stable so that the atomic beam intensity is stable.

evaporation is sufficiently slow that the potassium re-evaporates and is pumped off.

VII. Some Characteristics of the Detecting Wire

Important stuff here!

1. The tungsten detector wire is kept taut by springy stainless steel leads at its ends.

2. When a new wire is installed a positive emission current will be found when the current through the wire is such as to heat it to about 1400°K. This is due to impurities in the tungsten. As the temperature is raised, this positive current becomes quite large. These impurities must be gotten rid of before the wire is suitable for detecting potassium. This requires heating the wire to about 1800°K for a number of hours. For a tungsten wire 0.002" dia. positive ion emission starts at a current of about 0.20 amp. To be a satisfactory potassium atom detector the current must be increased to about 0.28 amp. It requires something like a day of heating with this current before the positive ion current drops to a sufficiently low value.

3. If the wire is heated too hot to hurry the process, there appears to be an effect on the wire that results in random fluctuations of emitted current later. It is recommended that a current no greater than 0.30 amp be used for a 0.002" dia. wire.

4. If the wire stays at room temperature for some time in a vacuum, it requires a time before the positive emission ceases after being heated and with no potassium beam. As a consequence, it is desirable that the recommended current be passed through the wire at all times, except, of course, when the apparatus is shut down for long periods of time.

VIII. The Vacuum System

1. A good mechanical fore-pump should be used.

2. Be sure water is circulating in the cooling coils of the diffusion pump before turning on the heater to heat the silicon oil. The power to the heater may be turned on right after the mechanical pump starts to evacuate the system.

3. It requires several hours to reach a suitably low pressure.

4. A Penning gauge is built into this apparatus. See experiment on the mass spectrometer for a description of this gauge.

5. A liquid nitrogen trap is also built into this apparatus. In actual practice, the addition of liq. N_2 to the trap causes only a small effect. Hence it normally is not used.

H. Victor Neher: one of the all-time great instrument makers!

H.V. Neher
July 1968.