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LIQUID HELIUM TARGET

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LIQUID HELIUM TARGET

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Abstract

A liquid helium target system has been built and used for the experiment on the reaction $^4He(\gamma,p)$. The target system has worked satisfactorily; the consumption rate of liquid helium is 360 *ml*/h and the cryogenic system retains liquid helium for about ten hours.

The structure, operation and performance of the target system are reported.

1. Introduction

The investigation on the two-nucleon correlation in the nucleus has been performed in the energy region of $\Delta(1232)$ resonance using a tagged photon beam of the 1.3 GeV electron synchrotron at Institute for Nuclear Study, University of Tokyo. $A(\gamma,p)$ reactions were measured for deuterium, beryllium, carbon and oxygen targets. From the results, experiments on the helium target were highly required, in which a clear result on the reaction mechanism was expected.

The liquid helium target is made by modifying the liquid hydrogen target of Whalin-Reitz type[1] used in the previous experiment. Since the latent heat of liquid helium is about twenty times smaller than that of liquid hydrogen, the heat inflow into the target must be decreased by about an order of magnitude for the practical use.

Here the structure, operation and performance of the target system are reported.

2. Plan of Reconstruction of the Target System

On the modification of the liquid hydrogen target, many points must be improved to complete a liquid helium target system capable for practical use. For this purpose, we set three requirements on the liquid helium target system; the endurance of the target, sufficiently low consumption rate of liquid helium, and accurate monitors.

The target system must, of course, endure the quite low temperature of liquid helium and the pressure difference of one atmosphere. In addition, they also bear with the rapid changes of temperature and pressure in the transfer operation. Particularly the appendix, which is the container of liquid target irradiated with the photon beam, must have a very thin wall. It seemed very difficult to satisfy the requirements above simultaneously. In the case of the liquid hydrogen target system, the appendix was made of Mylar film and was glued together with epoxy resin. Though the temperature of the liquid helium is much lower than that of liquid hydrogen, we decided to try the same type of the appendix as that in the liquid hydrogen target system.

For the practical use, the cryogenic system is hoped to retain liquid helium in the appendix for about half a day. Since the target system is not equipped with the refrigerator, liquid helium is transfered from the external Dewar bottle into the target system. Frequent transfer causes losses of both time and liquid helium. So we set our goal of the consumption rate of liquid helium at about 300 ml/h which corresponds to the retaining time of twelve hours.

In the transfer operation, an accurate monitor to detect that liquid helium reservoir is filled up is indispensable. In fact, at every stage of the test of the target system, it was the most difficult problem. We chose carbon resistors as a sensor and surveyed the best circumstance to use it.

3. The Structure of the Liquid Helium Target

The outline of the liquid helium target system is shown in Fig. 1-a. It is composed of an appendix, a liquid helium reservoir, a radiation shield, a liquid nitrogen container and a vacuum jacket.

The liquid helium target system doesn't have a refrigerator and stores liquid helium in the reservoir tank, from which liquid helium is supplied to the appendix. When the reservoir becomes empty, liquid helium is transfered from an external Dewar bottle to the reservoir through a transfer tube.

The outline of the liquid hydrogen target system used in the previous experiment is shown in Fig. 1-b. The following modifications are done on this liquid hydrogen target system to decrease the heat input.

a) The radiation shield is improved to be more effective. In the case of the liquid hydrogen target system, the radiation shield was made of copper cylinder. In the case of the liquid helium target system, it is changed to be a set of tanks filled with liquid nitrogen.

b) All pipes running from the head to the appendix are removed to decrease the heat input by conduction.

With these modifications, the heat input rate is decreased to be one fifth of that of the original target system and the cryogenic system keeps the liquid helium in the appendix for about 10 hours.

3.1 The Vacuum System

The vacuum jacket is a container of the inner target assembly. Inside of the jacket is evacuated for the insulation of heat.

The vacuum jacket is almost the same as that of liquid hydrogen target system, except that the emergency exhaust at the bottom of the jacket is eliminated. The pumping system is composed of a diffusion pump of 220 l/sec and a rotary pump of 250 l/min. The achieved vacuum pressure is 5×10^{-5} torr at room temperature and 2×10^{-5} torr after the liquid nitrogen container and the radiation shield are filled with liquid nitrogen. It becomes 2×10^{-6} torr after the reservoir is filled with liquid helium.

There is a window on the sidewall of the vacuum jacket through which the photon beam and the outgoing particles from the target pass. The angular range of the window, which is from +119° to −141°, puts restrictions on the measurement of the angular distributions of the reactions.

3.2 The Liquid Nitrogen Container and the Radiation Shield

The liquid nitrogen container is a cylindrical tank with an annular space containing 10.3 l and is made of stainless steel. It stores liquid nitrogen and supplies it to the radiation shield. At the center of the tank, along the center axis, a supporting pipe of the liquid helium reservoir goes down. The top of the liquid nitrogen container is silver-soldered to the supporting pipe of the liquid helium reservoir to decrease the heat conduction through the pipe into the liquid helium reservoir.

The radiation shield is a set of tanks surrounding the liquid helium reservoir and the appendix. The tanks are filled with liquid nitrogen, which is supplied from the liquid nitrogen container, to decrease the heat input into the liquid helium reservoir and the appendix by radiation.

In the case of the liquid hydrogen target system, the radiation shield was a copper cylinder connected to the bottom of the liquid nitrogen container and was cooled by conduction. However, it was not cooled down to the liquid nitrogen temperature. In the case of the liquid helium target system, the radiation shield is changed to be a set of tanks filled with liquid nitrogen located around the liquid helium reservoir and the appendix. The shape of the radiation shield is shown in Fig. 2 schematically. In this case, the radiation shield is cooled down to the liquid nitrogen temperature.

The whole surface of the radiation shield is covered with aluminized Mylar films to lower the emissivity of the surface. The interspace between the two tanks, where the appendix is located, is also covered with the aluminized Mylar film.

3.3 The Liquid Helium Reservoir

The liquid helium reservoir is a cylindrical tank with capacity of 3.6 l made of stainless steel. This reservoir stores liquid helium and supplies it to the appendix.

In the case of the liquid hydrogen target system, there were two pipes running from the bottom of the reservoir to the head of the vacuum jacket, as shown in Fig. 3-a. One was a needle valve with its guide pipe and the other was a gas exhaust pipe of the appendix. In addition, a liquid level sensor was inserted from the head of the vacuum jacket into the reservoir. These pipes caused a large heat conduction into the reservoir from the room temperature because they were not cooled with the liquid nitrogen. In order to reduce the heat input, all the pipes are removed. In addition, setting method of the liquid level sensor is changed to rise up from the bottom of the reservoir and the signal wires are extracted from the neck of the appendix as shown in Fig.3-b. The wires are cooled down by the liquid nitrogen container to prevent the heat conduction from the room temperature.

Since the needle valve is removed, the appendix is directly connected to the liquid helium reservoir. So liquid helium transfer into the reservoir must be done very carefully, because the appendix might be damaged due to rapid cooling and/or pressure rise.

3.4 The Appendix

The appendix is a liquid helium container irradiated with the photon beam. It is made of Mylar film of 125μm thick and each part is glued together with Armstrong[*)] , a kind of epoxy resin adhesive. The detailed description of the method how to make the appendix is given elsewhere[2)] .

The appendix has a cylindrical shape with a "neck" to support it as shown in Fig. 4. The size of the appendix depends on the experimental conditions. Considering the beam size, the energy loss of the emitted proton and the reaction cross section, the diameter and the length of the appendix are determined to be 4.0 cm and 11.0 cm, respectively.

The neck consists of Mylar film and a copper pipe. The Mylar film is glued to the copper pipe, and the copper pipe is soft-soldered to the bottom of the liquid helium reservoir to ensure the vacuum-tight connection even when it is cooled down to the liquid helium temperature.

3.5 The Monitors

The operation of the target system is classified into two states; one is a steady state, during which the measurement is carried out, and the other is a transient state during the liquid helium transfer. The target system is equipped with two types of monitors for each operation. The distribution of

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*) Armstrong A-4 ; Armstrong Products Co. Inc., Warsaw, Indiana.

them is shown in Fig. 1-a.

A vacuum gauge, a thermocouple and two liquid level sensors are mounted in order to watch the steady-state operation. Almost all troubles occuring on the target system cause pressure change, so that the vacuum gauge is a good sensor for troubles. A copper-constantan thermocouple is attached on the neck of the appendix to monitor the temperature of the appendix. The level of liquid helium is monitored with two level sensors. One is set at the 80 % level of the liquid helium reservoir capacity and the other 1.0 cm above the appendix. They are 1/8 watt carbon resistors made by Allen-Bradley Co. Ltd. They indicate resistance of 105 Ω at room temperature and 1.15 kΩ at the liquid helium temperature. When sufficiently high current flows through the resistor, the resistance in liquid helium is appreciablly different from that in helium gas of the liquid helium temperature. The thermal conductivity and the specific heat of helium gas is smaller than those of liquid helium, so that the cooling effect is smaller in gas than in liquid even if the temperature is the same. Consequentially, the temperature of the carbon resistor is higher in gas than in liquid as a result of the heat generation by itself, and the difference of the resistance appears. The resistance of the sensor becomes about 5 % smaller in helium gas than in liquid helium when the current of 1.5 mA is supplied to it. This transition of the resistance is quite easily detected by monitoring the current flowing through the resistor.

In order to detect that the reservoir is filled up with liquid helium in the transfer operation, two carbon resistors and a thermocouple are used. One resistor is set in the supporting pipe of the reservoir and the other is set in the head of the vacuum jacket. The current of about 10 μA is supplied to the resistors. In this case, since the current is low and only a little heat is generated in the resistors. the resistors are cooled down in gas as well as in liquid, so the difference of the cooling effect is not distinguishable and they detect the temperature itself. A copper-constantan thermocouple is set at the exit of the gas exhaust pipe. These monitors measure the temperature of outgoing helium gas. When the reservoir is filled up with liquid helium, the temperature of the outgoing gas becomes the liquid helium temperature. This change is detected by these sensors. The resistor set in the supporting pipe of the reservoir is the most sensitive and is usually used for judgement.

3.6 The Gas Circuit

The gas circuit has two purposes; one is to supply helium gas into the reservoir and the appendix in the pre-cooling stage, and the other is to let the helium gas out from the reservoir and the appendix.

Since both the needle valve and the gas exhaust pipe of the appendix are removed off the liquid helium reservoir, the gas circuit is very simplified. The circuit is shown in Fig. 5 schematically. There are only two holes at the head; one is a hole with a Wilson-seal to insert the transfer tube, and the other is a gas exhaust pipe of the reservoir and the appendix. The entrance hole for the transfer tube is closed in the steady-state operation. The gas exhaust pipe is connected to the distributer panel including an emergency valve, a valve to a vacuum pump, a pressure gauge and a gas flowmeter.

The emergency valve is used to exhaust helium gas quickly. The vacuum pump is to evacuate the inside of the reservoir and the appendix before the first transfer operation in order to replace the inside gas with dry helium gas completely. The pressure gauge measures the pressure of the outgoing helium gas. The flow meter is to measure the exhaust speed of helium gas. Next to the flowmeter, a bubbler is connected to prevent the air flow-back into the reservoir.

The transfer tube is also used for the gas flow in the pre-cooling stage. Through the tube, dry nitrogen gas, afterwards helium gas, flows into the reservoir and the appendix.

4. Preparations of the Target System

There are five stages before the steady-state operation; assembling, circuit connection, evacuation, pre-cooling, and liquid helium transfer. These preparations are described in this section.

4.1 Assembling

The necessary procedures for assembling the target system consist of the attachment of the appendix and the radiation shield, and setting them into the vacuum jacket. These procedures are described in the following.

1) Solder the appendix to the bottom of the liquid helium reservoir. Since the Mylar film and the epoxy resin are easily damaged by heat, the soldering must be done carefully. For protection against the heat, cover the appendix with wet asbestos during the soldering. However, the conduction through the copper pipe can't be avoided so that doing it quickly is the best way not to

damage the appendix.

2) Cleanse the reservoir and the appendix with aceton.

3) Mark the center points indicating the axis of the cylinder on the both endcaps of the appendix. These marks are used to align the target on the beam line.

4) Cover the appendix with the aluminized Mylar film.

In order to see the center marks and the liquid level in the appendix, make narrow slits on the aluminized Mylar film covering the both endcaps of the appendix.

Vacuum grease is suitable to paste the aluminized Mylar film on the appendix.

5) Solder a copper-constantan thermocouple on the copper part of the neck of the appendix. Also solder wires to the terminals of the level sensors. It is better to keep the length of the wires as short as about 16 cm to allow easy mounting of the radiation shield. They are extended later.

6) Cover the helium reservoir with aluminized Mylar film.

7) Cover the inner surface of the radiation shield facing to the liquid helium reservoir with aluminized Mylar film. At the same time, curtain the window of the radiation shield on the scattering plane with it. In order to see the center marks on the appendix, make narrow slits on the aluminized Mylar film where the photon beam passes.

8) Screw the radiation shield onto the bottom of the liquid nitrogen container.

9) Connect the liquid nitrogen container and the radiation shield tanks with copper pipes. Grease the connections in order to prevent the leakage of nitrogen when they are cooled down to the liquid nitrogen temperature.

10) Extend the wires from the thermocoulpe and level sensors to the terminals on the lid of the vacuum jacket and solder them to the terminals.

11) Cover the outer surface of the radiation shield and the liquid nitrogen container with the aluminized Mylar film. Bury the signal wires from the sensors under this Mylar film. Make narrow slits on this Mylar film where the photon beam passes.

12) Cover the inner surface of the vacuum jacket with the aluminized Mylar film. Curtain the window on the scattering plane with the aluminized Mylar film and again make narrow slits on the film where the photon beam passes.

13) Put the target assembly into the vacuum jacket.

The assembling procedure is finished now and the target is set on the beam line. Alignment of the target on the beam line is performed by looking at the center marks on the appendix with a transit compass through the slits made on the aluminized Mylar film.

4.2 Circuits Connection

1) Connect a vacuum gauge controller to the vacuum tube and set the controller near the target to watch it during the transfer operation. Send the output of the controller to the electronics room and record it on a paper chart.
2) Put the other contact of the thermocouple on the neck of the appendix into the Dewar vessel filled with ice and measure the voltage due to the thermoelectric force with voltmeter. Set the meter near the target to watch it during the transfer operation. Send the output voltage to the electronics room and record it.
3) Extend the signal wires of the level sensors to the electronics room and connect them to a monitor circuit*) which converts the resistance of the sensor to a suitable voltage. Record the outputs of the circuit on a paperchart.
4) Connect the gas exhaust pipe to the distributer panel.
5) Insert the transfer tube into the liquid helium reservoir through the hole at the top of the head. Then flow dry nitrogen gas into the reservoir through the transfer tube to drive moisture away.

4.3 Evacuation

The inside of the vacuum jacket is evacuated with a rotary pump and a diffusion pump. Vacuum pressure of about 5×10^{-5} torr is achieved after a day.

In some cases, the inner assembly of the target moves slightly after this evacuation. In that case, re-adjustment of the target position on the beam line is needed.

4.4 Pre-Cooling

After achieving the vacuum pressure of about 5×10^{-5} torr, liquid nitrogen is transfered into the liquid nitrogen container from the external Dewar bottle. The liquid nitrogen is supplied once a day in the pre-cooling stage. This cooling process is monitored with the thermocouple at the neck of the appendix. It takes about two days until the liquid helium reservoir

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*) For example, see appendix.

and the appendix are cooled down to be in the thermal equilibrium state. The temperature of the liquid helium reservoir is about 110 K and the vacuum pressure is 2×10^{-5} torr in this equilibrium state.

4.5 The First Liquid Helium Transfer

After the pre-cooling, liquid helium is transfered from a Dewar bottle to the liquid helium reservoir. The arrangement of the apparatus is shown in Fig. 6. In the first transfer, in which liquid helium is transfered into the empty reservoir of the temperature of 110 K, there are some additional procedures compared to the successive one in which liquid helium is transfered when there remains liquid helium in the reservoir. The procedures for the first transfer operation are described.

Before beginning the transfer operation, some preparations are needed.

- Change the flowing gas from nitrogen to helium and replace the gas in the appendix and the reservoir with helium.
- Evacuate the interspace of the transfer tube with a rotary pump.

Then set the liquid helium Dewar bottle with capacity of 100 l on a lift and begin the transfer operation.

1) Connect the signal wires of the carbon resistors for the transfer monitor to a monitor circuit similar to that of the liquid level sensors. Then connect the outputs of the circuit to the pen-recorder.
2) Disconnect the pipe between the gas exhaust pipe and the distributor panel to make the conductance for the outgoing gas as high as possible.
3) Set a thermocouple at the exit of the gas exhaust pipe to monitor the gas temperature. Connect the other contact of the thermocouple to the pen-recorder.
4) Stop the helium gas flow through the transfer tube and remove the transfer tube for a time.
5) Set the lift which the liquid helium Dewar bottle is on at a suitable position to insert the transfer tube into both the target and the dewar bottle.
6) Close the valve between the transfer tube and the rotary pump to prevent the oil flow back into the vacuum shield of the transfer tube.
7) Insert again the transfer tube into the liquid helium reservoir through the hole at the head and connect them air-tightly.
8) Insert the opposit side of the transfer tube into the Dewar bottle. Then lift up the Dewar bottle until the bottle and the tube are connected air-tightly.

9) Connect a helium gas cylinder to the Dewar bottle.

10) Flow helium gas from the cylinder into the Dewar bottle and apply pressure into the Dewar bottle to be about 100 mbar. Then liquid helium is transfered by this pressure from the Dewar bottle to the reservoir.

At the first transfer, the pressure must be increased slowly enough to prevent the break of the appendix by rapid cooling.

11) After a several minutes, there appears a sign on the recorder chart that the reservoir is filled up. Then release the pressure in the helium Dewar and stop the transfer of liquid helium.

12) Let down the Dewar bottle and remove the transfer tube.

13) Close the hole on the head air-tightly and connect the gas exhaust pipe to the distributer panel.

14) Measure the amount of the liquid helium left in the Dewar bottle with a carbon resistor.

With these procedures, the transfer operation is finished and the target system is in a steady state. Then we can start the measurement of, for example, $^{4}He(\gamma,p)$ reaction.

5. Example of Operation

Experiments on the reaction $^{4}He(\gamma,p)$ were carried out from March to June of 1984 using this liquid helium target system. The performance of the target system during the experiments is described in this section.

5.1 Monitoring

An example of the recorder chart for the monitor of steady-state operation is shown in Fig. 7. During the operation, vacuum, temperature and the resistance of the liquid level sensors in the reservoir and in the appendix are monitored.

The H point on the chart is a sign that the level sensor in the reservoir gets out of liquid helium, which means that liquid helium in the reservoir decreases to be 80 % of the reservoir capacity. The L point indicates that the level sensor at the neck of the appendix gets out of liquid helium. It took about twenty minutes from the time of L point to the time when liquid helium in the appendix bigins to diminish.

One division on the chart corresponds to thirty minutes, so that it was about 8 hours from H point to L point. It was about 2 hours from the transfer to the H point, so that the measurement of about 10 hours could be continued between transfers. This time interval of 10 hours was almost the same through the whole period of the experiment.

5.2 Consumption Rate

The capacity of the liquid helium reservoir is 3.6 *l*. The liquid helium in the reservoir was consumed out in 10 hours, so that the consumption rate of the liquid helium was 360 *ml/h*. Though this consumption rate was a little higher than that planned, it was tolerable.

With this time interval of 10 hours, about ten times of the transfer operations were done in the experimental period of one week. As is described later, about 8 *l* of liquid helium was consumed in one transfer operation, so about 80 *l* of liquid helium was needed in one week. The Dewar bottle of 100 *l* capacity was used in the experiment, and we could afford to do the experiment of one week with one bottle.

5.3 Liquid Helium Transfer

When L point appeared on the recorder chart, the measurement was stopped and the transfer operation was started. It took about 30 minutes to do the transfer operation. The transfer pressure was about 100 mbar, measured with a pressure gauge of the Dewar bottle, and the reservoir was full in 5 ~ 6 minutes.

An example of the monitoring chart during the transfer operation is shown in Fig. 8. The curves are the output of the two carbon resistors and the thermocouple. The thermocouple, which was set at the end of the helium gas exhaust pipe, was sensitive to the amount of gas flow. Seeing the curve, we could know whether the transfered liquid helium stayed in the reservoir as liquid or it vaporized immediately, so that approximate stage of the transfer was known.

The changes indicated by the arrows S on the chart, which occured at the same time, are the sign that the liquid helium reservoir is filled up. The carbon resistor set in the supporting pipe of the reservoir detected it most sensitively.

In usual case, about 8 *l* of liquid helium was consumed to fill the reservoir, 4.5 *l* of which were transfer loss. This extra liquid helium may be consumed to cool down the transfer tube, the reservoir and its supporting pipe. In addition, the stop signal on the chart may tend to appear a littel after the reservoir is filled up.

The transfer efficiency seems to be very sensitive to the speed of the pressure increase applied to the Dewar bottle. Though the average of the amount of liquid helium consumed in the successive transfer operations was about 8 l, the value varied from 5 l to 10 l case by case. In every transfer operation, the final pressure applied to the Dewar bottle was 100 mbar, so this variation may be due to the speed of the pressure increase. The quantitative estimation of the relation between the transfer pressure and the transfer loss is not yet made.

In the first transfer, about 10 l of liquid helium was consumed. So, about 2 l was consumed to cool down the liquid helium reservoir from the temperatureof 110 K to liquid helium temperature.

5.4 Endurance

Through the experimental period, nealy fifty times of the transfer operation were done, five of which were the first transfer. The appendix, especially the epoxy-resin, stood not only the low temperature and high tension but also rapid change of temperature.

6. Comparison of Consumption Rate of Liquid Helium between the Measured Results and the Calculations

The consumption rate of the liquid helium is measured to be 360 ml/h. In order to check whether there are any unknown heat sources, this value is compared with the calculation.

6.1 Conduction

There are thre conducting materials known from the plan of the target; the supporting pipe of the liquid helium reservoir, the helium gas inside the pipe, and the signal wires of the thermocouple and the level sensors.

a) Supporting pipe of the reservoir

The pipe is made of stainless steel and the size of it is 38 mm diameter and 0.5 mm thick. The length from the reservoir (liquid helium temperature) to the thermal contact point to the liquid nitrogen container (liquid nitrogen temperature) is 330 mm. Then the heat flow through the pipe is calculated to be 0.062 W as follows;

$$\frac{dQ}{dt} = \frac{S}{L}\left\{\int_{0K}^{77K} K(T)dT - \int_{0K}^{4.2k} K(T)dT\right\} = \frac{0.60cm^2}{33cm} \times (3.4W/cm - 6.0\times 10^{-3}W/cm)$$
$$= 0.062\ W \qquad (1)$$

where S : cross section of the pipe,
L : length of the pipe,
$K(T)$: thermal conductivity of the pipe.

b) Helium gas in the pipe

Since the gas inside the pipe is cold at the bottom and warm at the top, we ignore the convection here and take only conduction into consideration. The tempreature of the helium at the hot side (thermal contact point to the liquid nitrogen container) is measured to be the liquid nitrogen temperature. Then the heat flow through the gas is calculated as follows;

$$\frac{dQ}{dt} = \frac{11.3cm^2}{33cm} \times 2.5\times 10^{-2}W/cm = 0.009\ W \qquad (2)$$

c) Signal wires

There are three pairs of wires; one for the thermocouple and two for the level sensors. The thermal conductivity of constantan is about one-hundredth of that of copper, so that we ignore it here and take five copper wires into consideration.

The wires have contact with the radiation shield and are cooled down to be the liquid nitrogen temperature there. The length of the wires from the appendix to the radiation shield is about 16 cm and the cross section of the copper wire is 0.079 mm^2, so that

$$\frac{dQ}{dt} = \frac{0.079mm^2 \times 5}{16cm} \times (710W/cm - 9W/cm) = 0.173\ W \qquad (3)$$

6.2 Radiation

The heat input by the radiation occurs between the helium reservoir and the radiation shield and between the appendix and the window through the narrow slits made on the Mylar curtain. There is a formula calculating this radiation;

$$\frac{dQ}{dt} = E\sigma A(T_h^4 - T_l^4) \qquad (4)$$

where E : shape-modified emissivity,
σ : Stephan-Boltzmann constant,
A : area of the surface,
T_h : temperature of the hot surface,

T_l : temperature of the cold surface.

The emissivity of the pure-surfaced aluminized Mylar film is about 0.04. However, the surface may be poluted with oil from the vacuum pump, so we assume 0.1 as shape-modified emissivity here.

For the radiation between the reservoir and the radiation shield, the total area of the reservoir (and the appendix) is summed up to be 2050 cm^2. The temperatures are, of course, 77 k and 4.2 K. Then heat input by radiation is calculated as follows;

$$\frac{dQ}{dt} = 0.1 \times 5.67\times10^{-12}W/cm^2K^4 \times ((77K)^4-(4.2K)^4) \times 2050cm^2 = 0.041\ W \qquad (5)$$

The area of the slits is 10 cm^2. The temperature of the hot side is room temperature (~ 280 K). Then heat input through the slits is calculated to be

$$\frac{dQ}{dt} = 0.1 \times 5.67\times10^{-12}W/cm^2K^4 \times ((280K)^4-(4.2K)^4) \times 10cm^2 = 0.035\ W \qquad (6)$$

So the total heat input by radiation is summed up to be 0.076 W.

6.3 Heat Generated by the Resistors

The carbon resistors set in the reservoir and in the appendix generate some heat. Their resistance at the helium temperature is 1.15 kΩ and current of about 1.5 mA is supplied to them. Then the heat generated is

$$\frac{dQ}{dt} = 1.15k\Omega \times (1.5mA)^2 \times 2 = 0.005\ W \qquad (7)$$

6.4 Comparison

Since the vacuum pressure in the jacket is sufficiently low, we ignore the heat input by both conduction and convection through the residual gas in the jacket.

The calculated heat inputs are converted into the consumption rate of liquid helium using latent heat and specific heat of helium. The heat input by radiation, by conduction through wires, and that generated by resistors are compensated only by latent heat of liquid helium, which is 21 J/g, since they directly flow into the reservoir and the appendix. On the other hand, those by conduction through the supporting pipe and the gas inside the pipe are compensated by both latent heat of liquid helium and heat capacity of helium vapor, which is 393 J/g when the temperature of the vapor rises up from 4.2 K to 77 K, since the supporting pipe is cooled by the helium gas vaporized in the reservoir. Then heat input are interpreted into consumption rate as follows,

conduction through the pipe and gas	0.071 W	=	5 *ml/h*
conduction through the wires	0.173 W	=	237 *ml/h*
radiation	0.076 W	=	104 *ml/h*
heat generated by the resistors	0.005 W	=	7 *ml/h*
total	0.325 W	=	353 *ml/h*

This calculated value of 353 *ml/h* agrees quite well with the measured value of 360 *ml/h*. So we can conclude, though the emissivity is assumed, that there is no excess heat input.

7. Summary

The target system was used in the experiment on the reaction $^4He(\gamma,p)$ for two months and it operated very stably with low consumption rate of liquid helium. The target experienced the transfer operation of nearly fifty times and had no vacuum troubles. So the appendix, made of the Mylar film and the epoxy-resin adhesive, proved to stand the practical use in such very cold circumstances with high machanical tension. The consumption rate of 360 *ml/h* made possible to achieve the transfer interval of about half a day. The monitoring system worked so well that there were no difficulty caused by the lack of information. However, the transfer tube was very hard to deal with, and it may be improved. As a whole, the target system worked satisfactorily.

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Appendix. Monitor Circuit

The change of the resistance of the liquid level sensors is so large that you don't have to use a bridge circuit to detect the transition. We used such simple circuit as shown in Fig A-1. The output voltage of the circuit was recorded on a paper-chart recorder.

Similar circuit is used to monitor the resistance of the transfer monitors. Only the resistor built in the circuit is changed to be that of much high resistance to decrease the current to be 10 μA.

Mr.Sudo made us an alarm circuit which detects the transition of the resistance of the monitors and rings a buzzer. The circuit is shown in Fig. A-2.

Refferences

1) E.A.Whalin and R.A.Reitz, Rev.Sci.Instr. 26(1955)59
2) T.Kitami, H.Okuno and K.Takamatsu, INS-TH-61

Figure Captions

Fig.1-a The outline of the liquid helium target system.
The distribution of the monitors is also shown.

Fig.1-b The outline of the liquid hydrogen target system.

Fig.2 The shape of the radiation shield.

Fig.3-a The heat-conducting materials in the case of the liquid hydrogen target system.

Fig.3-b The heat-conducting materials in the case of the liquid helium target system.

Fig.4 The shape of the appendix.

Fig.5 The outline of the gas circuit.

Fig.6 The whole setup for the liquid helium transfer operation.

Fig.7 An example of the recorder chart of the steady-state operation.

Fig.8 An example of the recorder chart of transfer monitors. The curves are of thermocouple (TC), the resister in the pipe(PIPE), and that in the head (HEAD). The meaning of the arrows are as follows;

1 : monitors are switched on,
2 : transfer pressure is turned on,
3 : liquid helium begins to be transfered,
4 : liquid helium begins to be stored,
S : the reservoir is filled up,
5 : transfer pressure is released.

Fig.A-1 A monitor circuit for level sensors.

Fig.A-2 An alarm circuit for the detection of the liquid helium decrease.

Ⓐ APPENDIX
Ⓓ BEAM DUCT
Ⓖ GAS EXHAUST PIPE
Ⓗ liq. He RESERVOIR
Ⓙ VACUUM JACKET
Ⓝ liq. N_2 CONTAINER
Ⓡ RADIATION SHIELD
Ⓣ SIGNAL TERMINALS
Ⓦ MYLAR WINDOW

L_1, L_2 } LIQUID LEVEL MONITORS
TC THERMOCOUPLE
T_1, T_2, T_3 } TRANSFER MONITORS

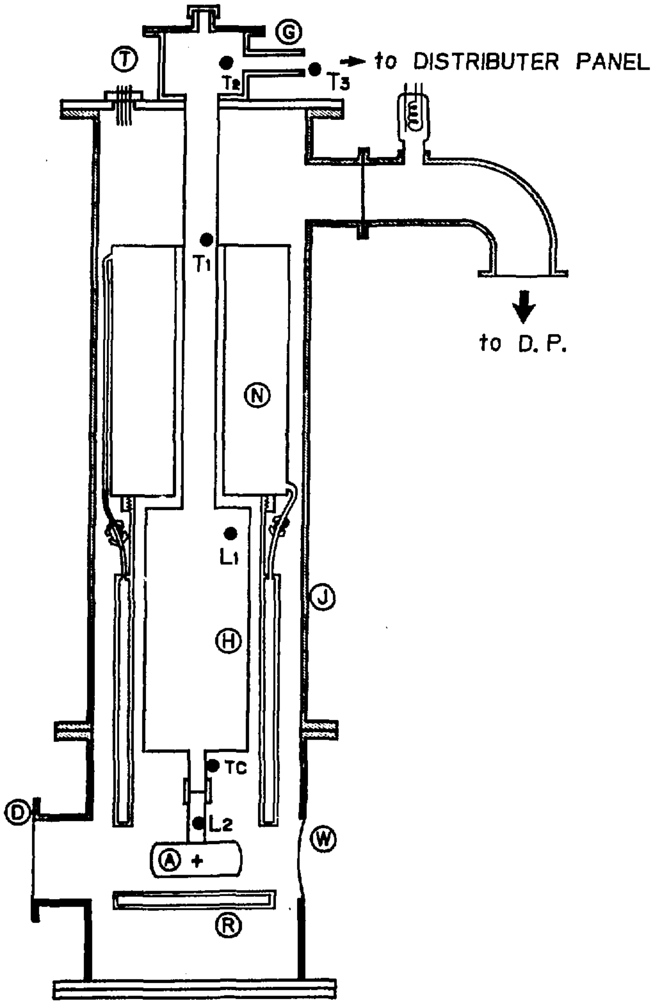


Fig. 1-a

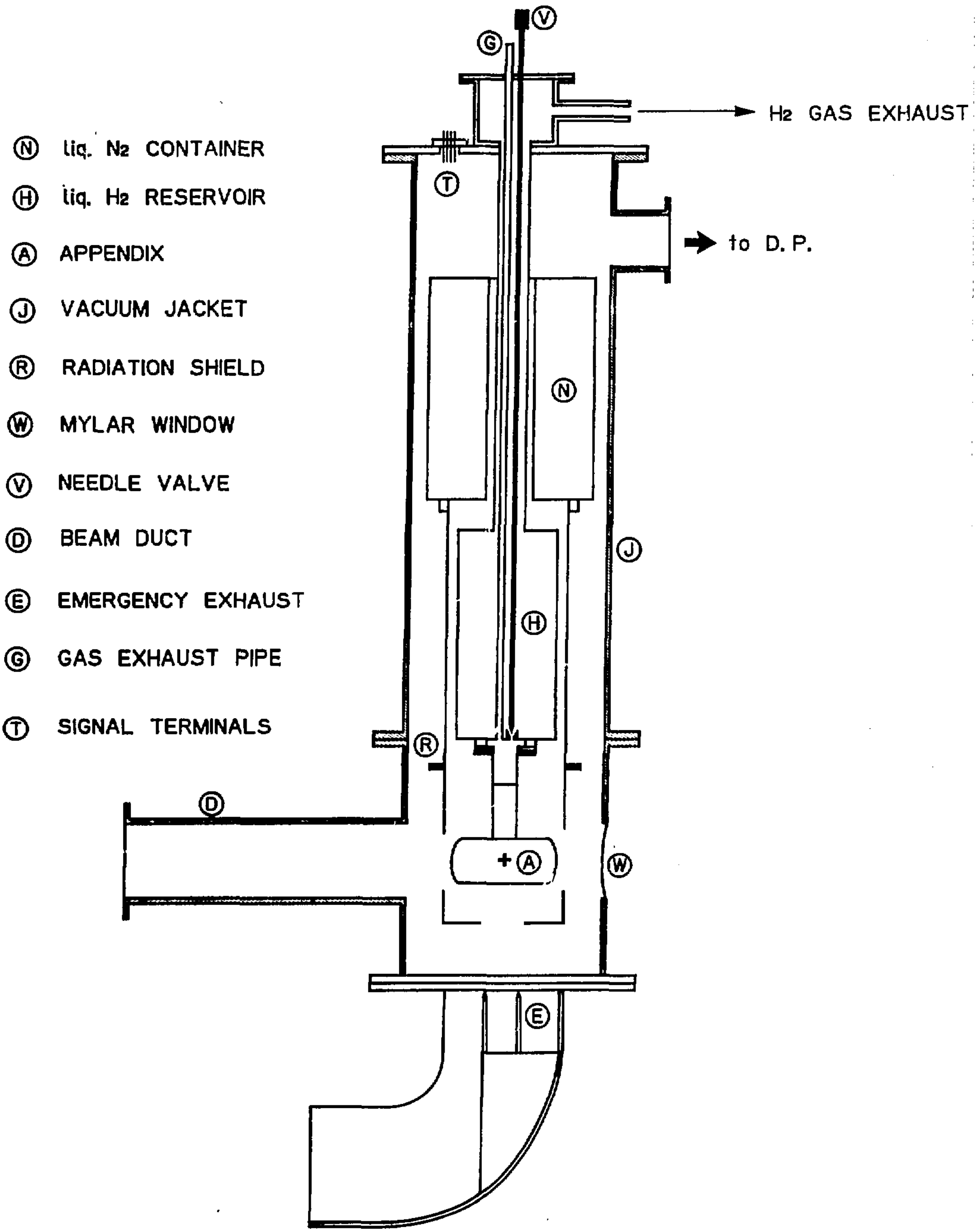

Ⓝ liq. N2 CONTAINER
Ⓗ liq. H2 RESERVOIR
Ⓐ APPENDIX
Ⓙ VACUUM JACKET
Ⓡ RADIATION SHIELD
Ⓦ MYLAR WINDOW
Ⓥ NEEDLE VALVE
Ⓓ BEAM DUCT
Ⓔ EMERGENCY EXHAUST
Ⓖ GAS EXHAUST PIPE
Ⓣ SIGNAL TERMINALS
H2 GAS EXHAUST
to D. P.

Fig. 1-b

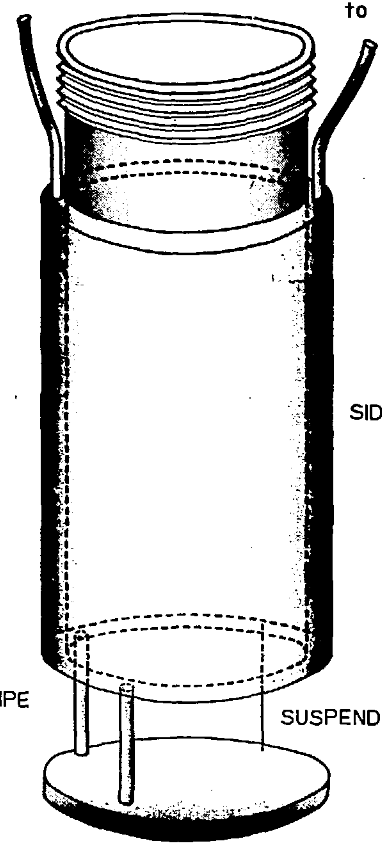

to lip. N2 CONTAINER
SCREW
to liq. N2 CONTAINER
SIDEWALL TANK
PIPE
SUSPENDING WIRE
BOTTOM TANK

Fig. 2

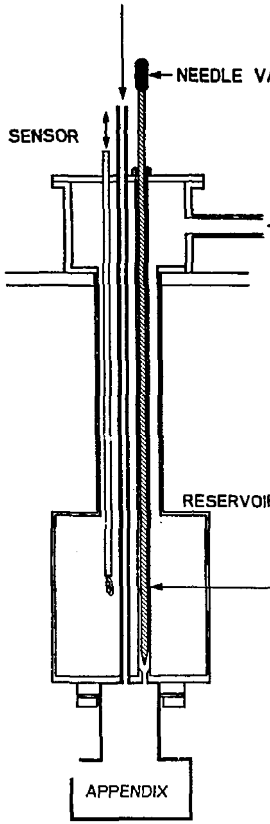

GAS EXHAUST PIPE OF APPENDIX
NEEDLE VALVE
LEVEL SENSOR
GAS EXHAUST PIPE
OF RESERVOIR
RESERVOIR
GUIDE PIPE OF
NEEDLE VALVE
APPENDIX

Fig. 3-q

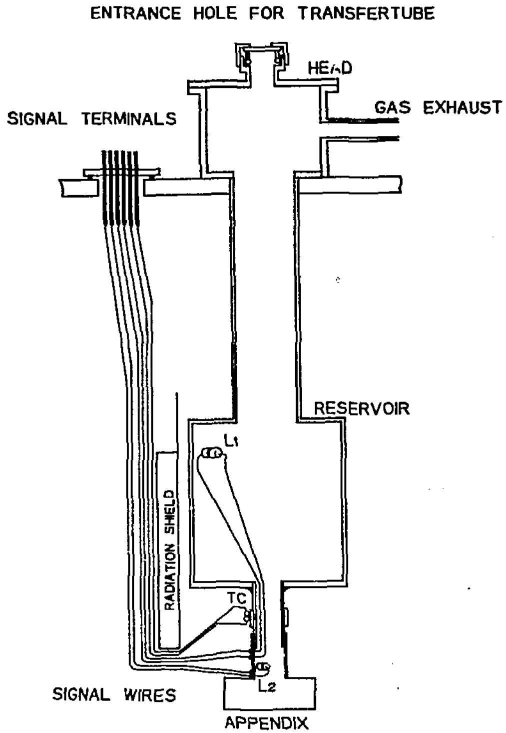
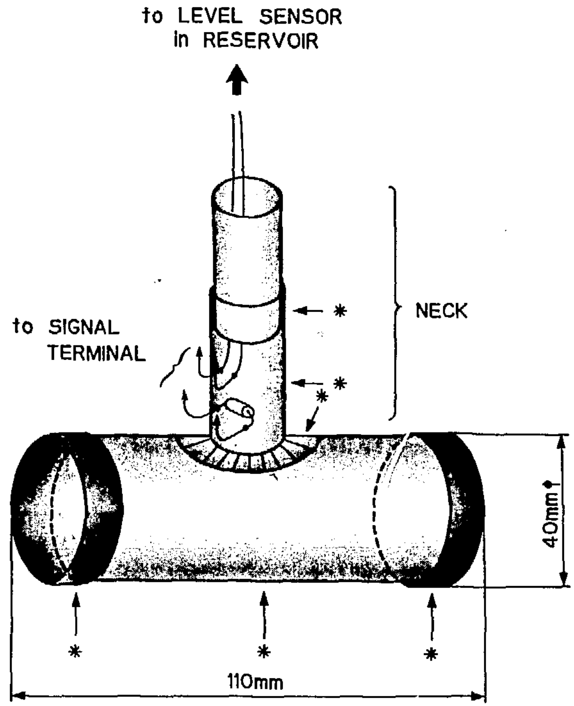


Fig. 3-b



* ---- Glued with ARMSTRONG

Fig. 4

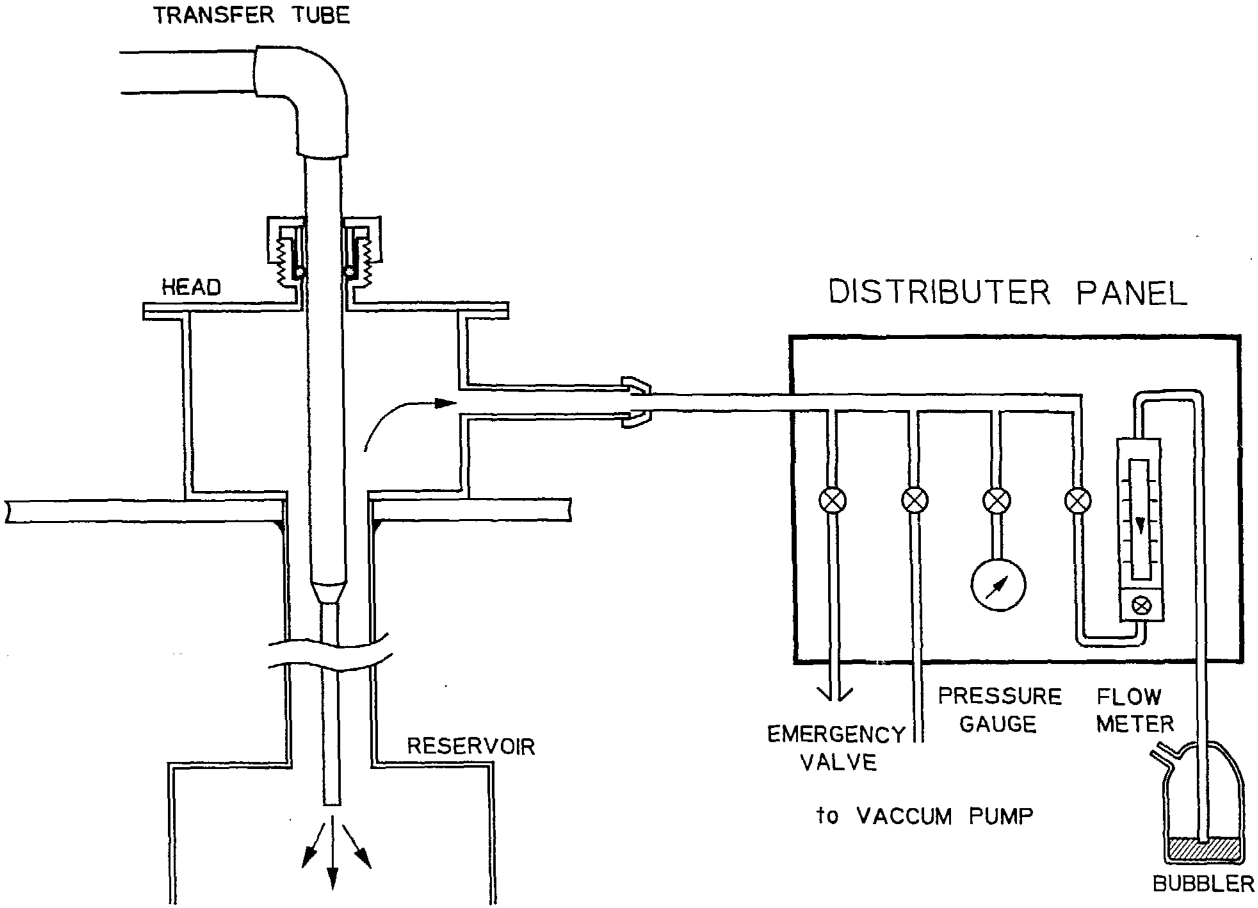

TRANSFER TUBE
HEAD
DISTRIBUTER PANEL
EMERGENCY VALVE
PRESSURE GAUGE
FLOW METER
to VACCUM PUMP
RESERVOIR
BUBBLER

Fig. 5

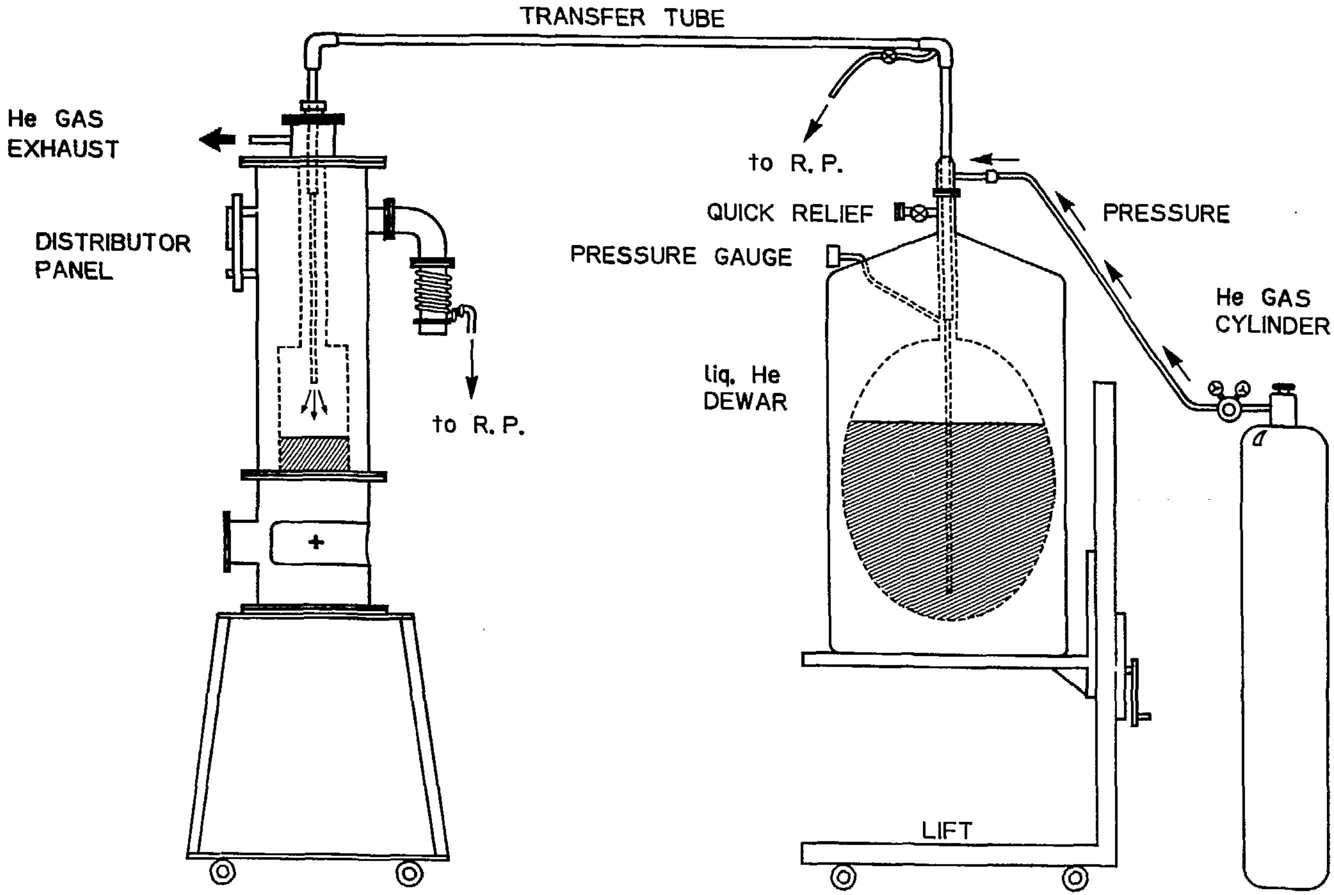

TRANSFER TUBE
He GAS
EXHAUST
DISTRIBUTOR
PANEL
to R. P.
to R. P.
QUICK RELIEF
PRESSURE GAUGE
PRESSURE
He GAS
CYLINDER
liq. He
DEWAR
LIFT

Fig. 6

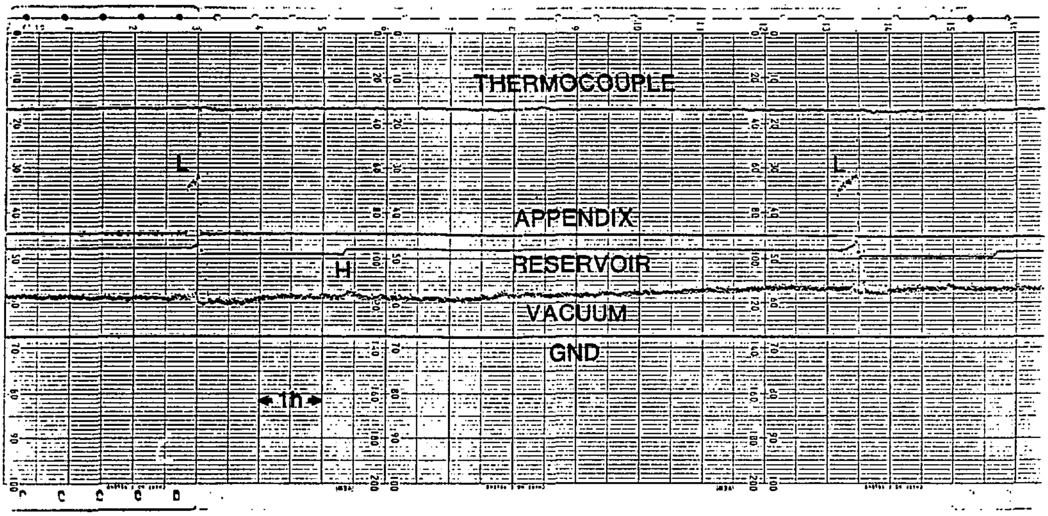

THERMOCOUPLE
L
L
APPENDIX
H
RESERVOIR
VACUUM
GND
1h

Fig. 7

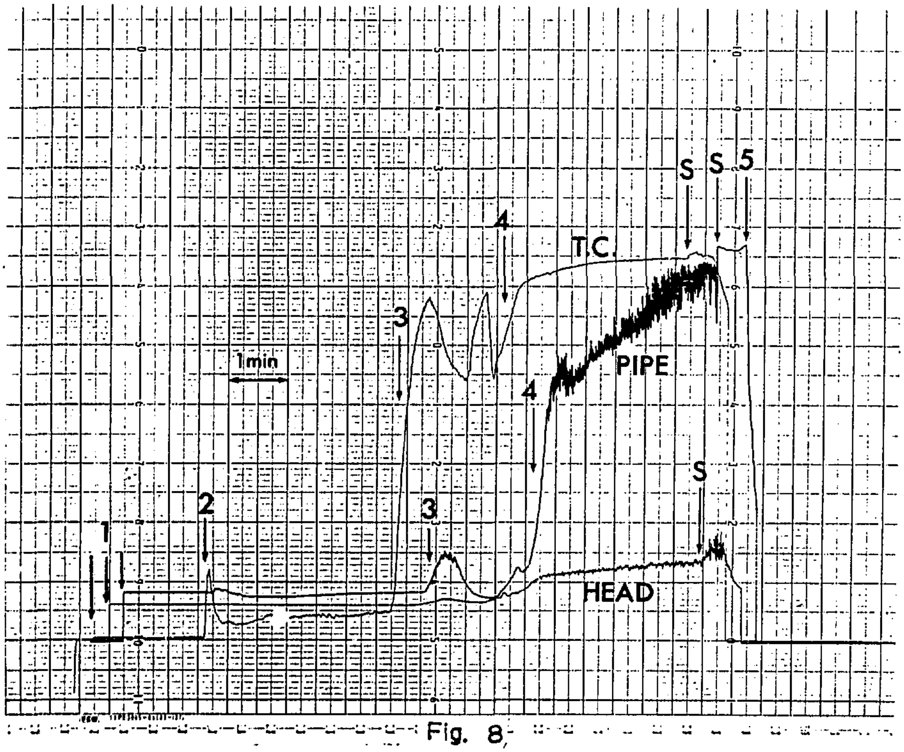

S
S
5
4
T.C.
3
1min
PIPE
4
S
2
3
1
HEAD

Fig. 8

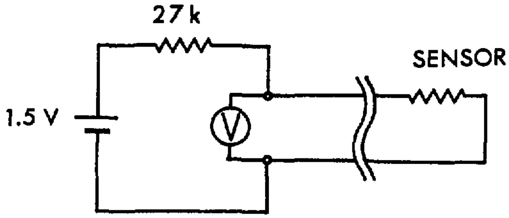

27k
SENSOR
1.5 V
V

FIG. A–1

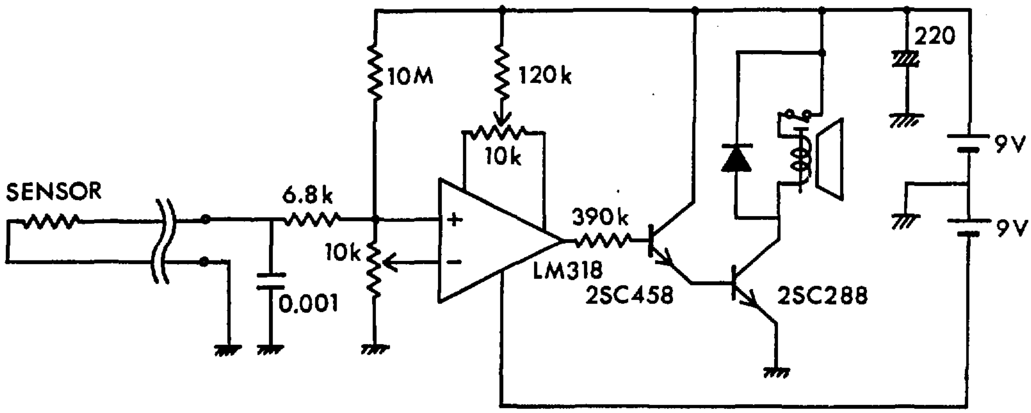

220
10M
120k
10k
9V
SENSOR
6.8k
390k
+
–
9V
10k
LM318
2SC458
2SC288
0.001

FIG. A–2