C.P. No. 106
(14,400)
(14,562 (Addendum))
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

A Frost Point Hygrometer for Supersonic Wind Tunnels

By

D. Beastall and A. Winyard

LONDON: HER MAJESTY'S STATIONERY OFFICE

1953

Price 1s. 6d. net

C.P. No. 106

Technical Note No. Aero 2114

July, 1951

ROYAL AIRCRAFT ESTABLISHMENT

A frost point hygrometer for supersonic wind tunnels

by

D. Beastall
and
A. Winyard

SUMMARY

This note describes a frost point hygrometer suitable for measuring the water vapour content of the air in supersonic wind tunnels at any stagnation pressure within their present range of operation. It uses CO_2 as a coolant and is economical in construction and operation.

LIST OF CONTENTS

LIST OF ILLUSTRATIONS

1 Introduction

In order to avoid spurious readings in supersonic wind tunnel tests it is essential to control the humidity of the air in the tunnel to some small value. This note describes a frost point hygrometer suitable for measuring humidities down to at least 0.0005 lb of water/lb of air over the range of pressures at which variable density wind tunnels operate. This requires a coolant capable of giving a minimum temperature of -40°C if the tunnel is to be operated at pressures down to 2.5 lb/sq in abs. with control to any intermediate temperature up to 0°C or above. The coolant used is carbon dioxide throttled from a high pressure cylinder.

The main advantages of this hygrometer are:-

1. Simplicity and cheapness of construction and operation.

2. Speed with which a frost point can be obtained (especially desirable for intermittent tunnels).

3. Freedom from leaks (essential at pressures less than atmospheric).

4. Availability of coolant.

5. Fine degree of control of temperature.

The hygrometer described here is in operation in the 9" x 9" supersonic wind tunnel at the R.A.E. and has been used for a short time without any serious troubles.

A more elaborate form employing CO_2 coolant is in use in America and is described in Ref. 1.

2 Description of hygrometer

Fig.1 is a detailed drawing of the hygrometer. It consists essentially of an arrangement for cooling a metal disc over which is passed the air whose humidity is required. The formation of frost is noted visually; the temperature of the disc at which frost is deposited on it is measured by a thermocouple, and the pressure of the air in the hygrometer is measured directly from a gauge. From this information the water content of the air can be derived using the chart in Fig. 2 reproduced from Ref. 2.

More specifically the construction and operation of the hygrometer is as follows:-

It is connected (see Fig.1) to a high pressure carbon dioxide cylinder, the CO_2 expands through a jet formed by a 6" length of 0.5 mm outside diameter stainless steel hypodermic tubing and impinges on the underside of a brass disc. Control of the temperature of the gas is by means of the pressure in the expansion chamber and this is regulated by the control valve (a needle valve). Fig. 3 shows the relationship between the pressure and temperature of the CO_2 when expanded from high pressure. It is essential during operation to keep the pressure in the expansion chamber above the triple point (approximately 5 atmospheres) in order to avoid choking the jet with solid CO_2. This, therefore, is the lower limit of operation of the hygrometer and is -70°F (-56.7°C). The expansion chamber pressure is recorded on an air pressure gauge.

The tunnel air is directed onto the top of the disc from a $\frac{1}{8}$" diameter inlet pipe and is returned through the air outlet. To facilitate the observation of frost the top of the disc has a matt black finish. The disc is made of brass and is insulated from the body of the hygrometer by fibre washers to prevent excessive dissipation of the cooling effect of the CO_2. The temperature of the disc is measured by means of a copper-constantan thermocouple junction (not shown in Fig.1) soldered to the upper surface of the disc. The hole through which the thermocouple leads were taken was made airtight by the use of araldite. The lower cylindrical part of the hygrometer was originally intended as a filter to reduce the water content of the CO_2 passing through the jet and thus reduce the possibility of icing up. It was found to be superfluous but has been left simply as a housing for the 6" length of 0.5 mm tubing comprising the jet.

Fig.4 gives diagrammatically the layout of the installation on the tunnel. Pipes are connected to the settling chamber and return circuit of the tunnel and thus provide a pressure difference for passing the air through the hygrometer. The pressure gauge (in this case a mercury barometer capable of reading pressures in the range of tunnel operating stagnation pressures) gives the air pressure in the hygrometer. The thermocouple is connected to a millivoltmeter (scale 0-4 mv) the reference junction being immersed in transformer oil in a thermos flask. The thermocouple was calibrated so that the disc temperature corresponding to the millivoltmeter reading was known.

Throughout the installation attention has been paid to the elimination of leaks especially on the inlet side of the airline to the hygrometer and the hygrometer itself has been subjected to a pressure test at 1,500 lb/sq in. to ensure that there is no leak of CO_2 to the upper surface of the disc.

3 Determination of the water vapour content of a sample of air

Allow the tunnel air to flow through the hygrometer by opening the taps in the inlet and outlet pipe lines. With the control valve closed, open the CO_2 cylinder valve, the expansion chamber pressure will then be the cylinder pressure and no cooling of the disc will take place. Now by opening the control valve slowly the temperature of the disc can be lowered until frost appears; the reading of the millivoltmeter at which this occurs is then noted. The temperature of the reference junction and the air pressure in the hygrometer are then required. When the frost point temperature has been calculated, the water vapour content can be derived using Fig.2. The operating time for obtaining a frost point should not be more than half a minute. When closing the CO_2 cylinder valve ensure that the control valve is set above 5 atmospheres to prevent blocking of the jet by solid CO_2.

4 Further development

It should be realised that the arrangement described in this note is the outcome of a very short development programme and refinements may be made as experience is gained in its operation. Only the main dimensions are given in Fig. 1 since the successful operation seems to depend only on a few dimensions. One important point to note in the construction is that the CO_2 outlet should be large compared with the size of the jet to prevent solid CO_2 blocking the outlet. The only maintenance at present carried out is the periodical drying out of the hygrometer to prevent the accumulation of water deposited by the CO_2. The upper and lower limits of cylinder pressure which cover the range of satisfactory operation of the hygrometer are not known at present. Perhaps the only major modification which seems desirable is the installation of an automatic method of recording frost to eliminate the human error in visual observation.

Acknowledgement

The construction and installation of the hygrometer are due to Mr. N. Searle who also offered helpful suggestions during its development.

REFERENCES

Ref. No.	Author	Title, etc.
1	T.L. Wheeler H.O. McMahan	Instrument for measuring water-vapour content in aviator's oxygen. OSRD 5151. May 1945.
2	R.V. Hensley	Mollier diagrams for air saturated with water vapour at low temperatures. NACA T.N. 1715.

Addendum to Tech. Note No. Aero 2114

November, 1951

ROYAL AIRCRAFT ESTABLISHMENT

A frost point hygrometer for supersonic wind tunnels

by

D. Beastall
and
A. Winyard

ADDENDUM

Since the issue of Tech. Note Aero 2114, satisfactory operation of the hygrometer has been found to depend on the temperature of the CO_2 cylinder being above a certain value which is roughly 25°C. This temperature determines whether any moisture in the CO_2 will be deposited as ice in the jet of the hygrometer during operation, thus causing blockage.

If we treat the flow of the CO_2 as a simple fluid flow problem the minimum temperature attainable in the jet can be expressed in terms of the temperature (T_o) of the CO_2 in the cylinder. The jet is acting as the throat of a supersonic nozzle and the temperature in the jet will be that corresponding to sonic velocity of the CO_2. This minimum temperature, T, is given by the relation

$$T = T_o \left(1 + \frac{\gamma - 1}{2}\right)^{-1}$$

$$= T_o \times (1.165)^{-1} \qquad (1)$$

Thus if T_o is above 45°C, T will be above 0°C and ice will not form in the jet. This. however, assumes no supersaturation of the water vapour in the CO_2. In practice it has been found that successful operation of the hygrometer is possible with cylinder temperatures of round about 25°C or above.

Wt.2078.CP106.K3. *Printed in Great Britain.*

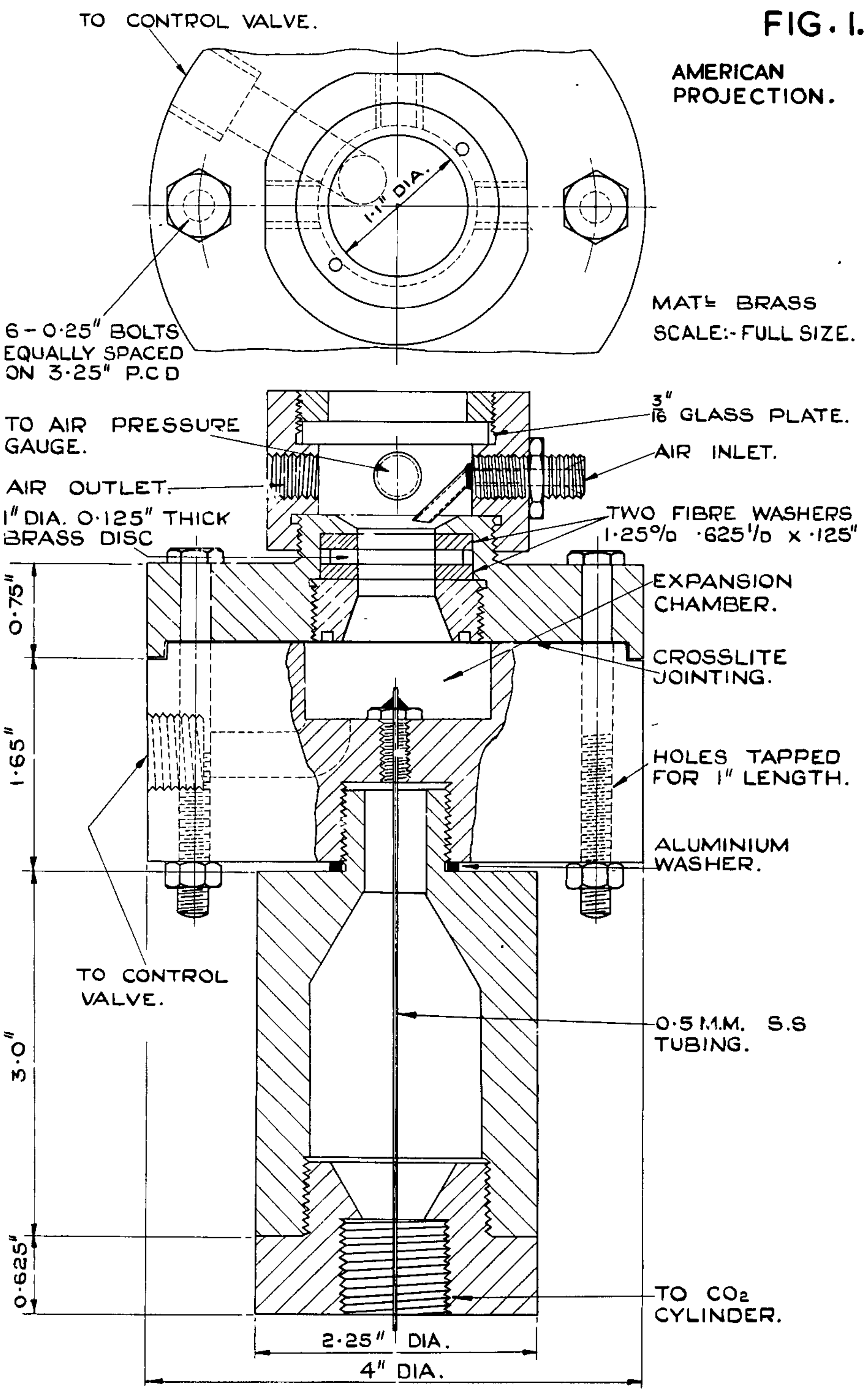

FIG. I. FROST POINT HYGROMETER.

FIG.2

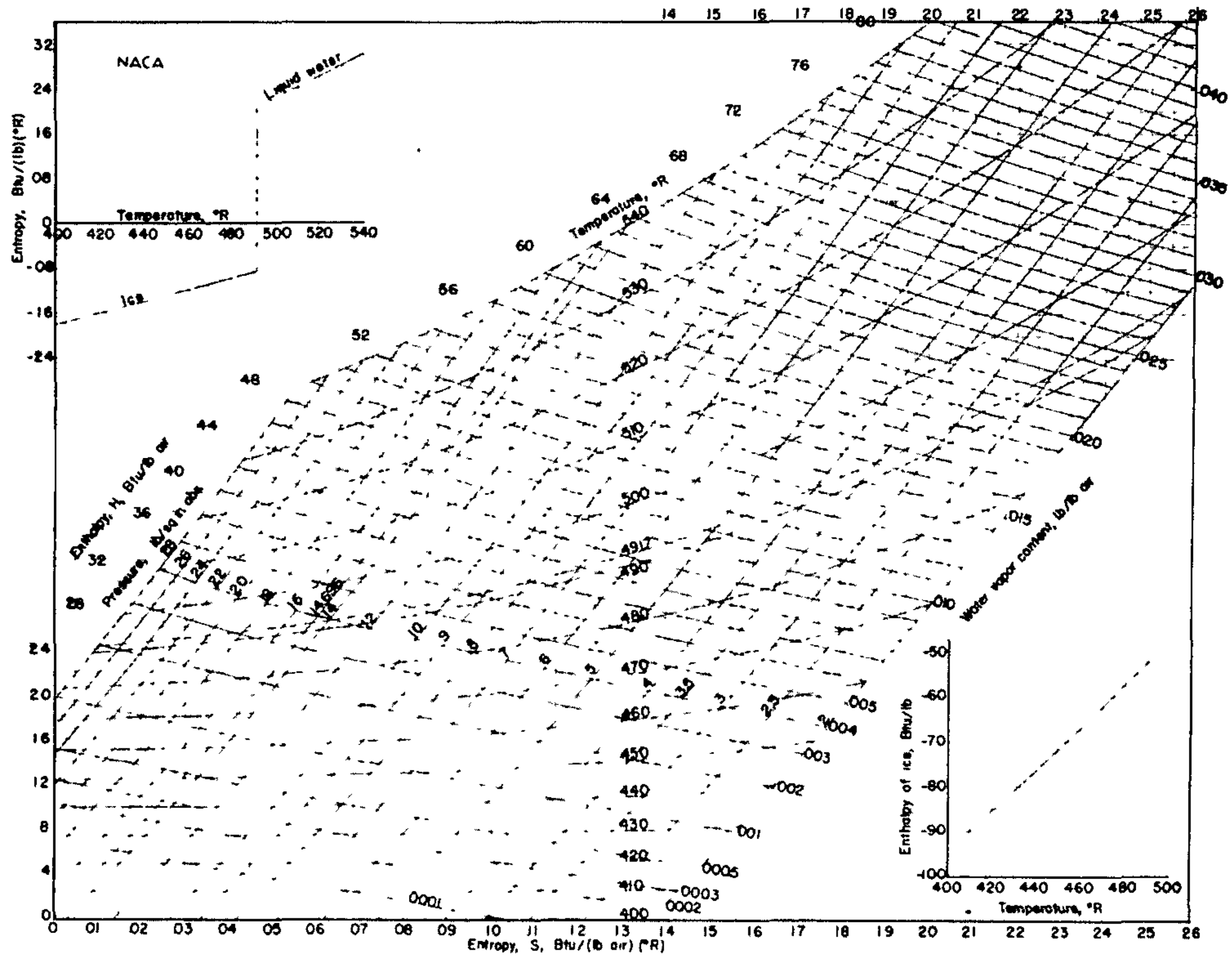

FIG.2. MOLLIER DIAGRAM FOR AIR SATURATED WITH WATER VAPOR AT VAPOR-SOLID EQUILIBRIUM FOR SUBFREEZING TEMPERATURES

FIG. 3.

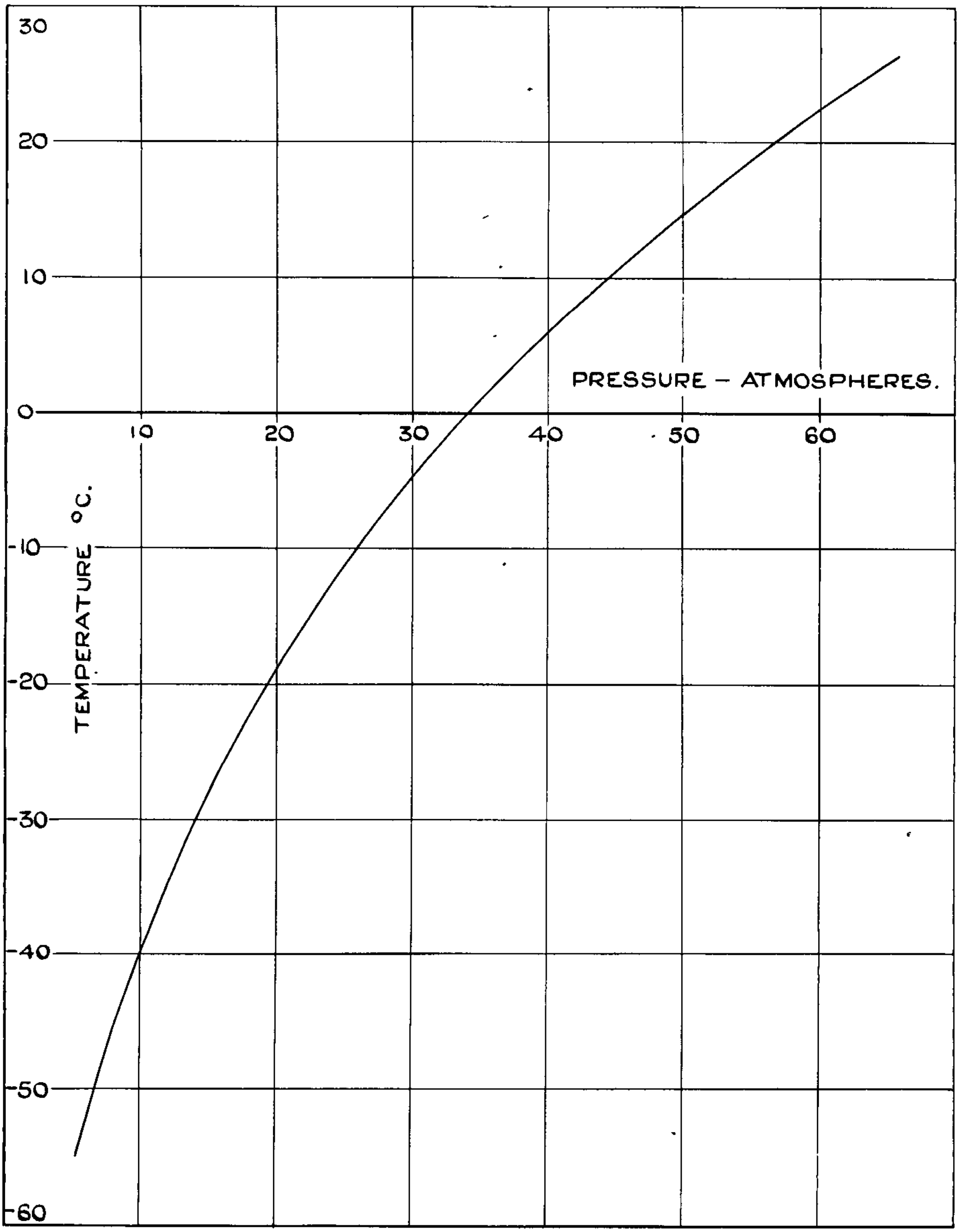

FIG. 3. VAPOUR PRESSURE OF CO_2.

FIG.4.

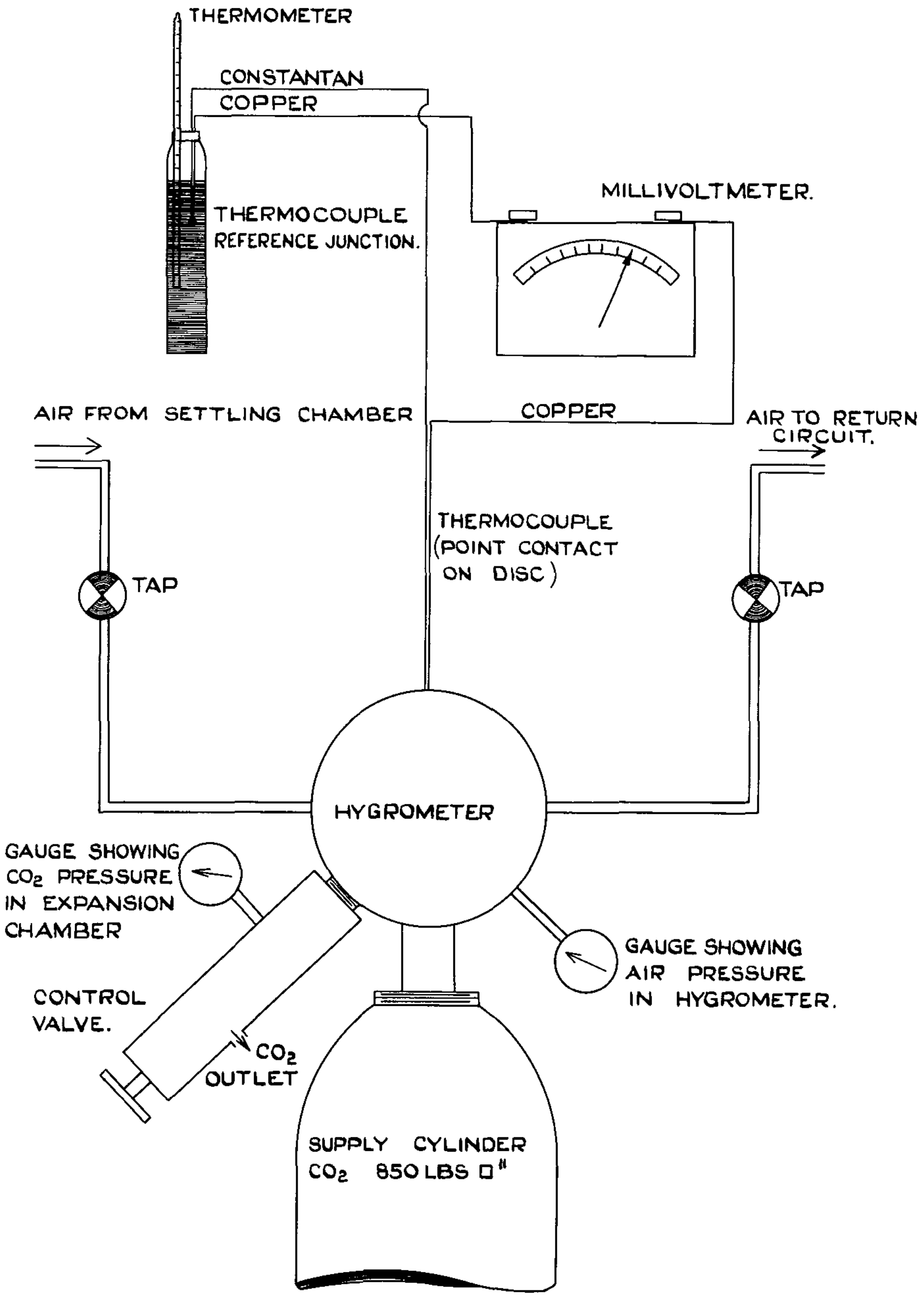

FIG. 4. HYGROMETER INSTALLATION.

C.P. No. 106
(14,400)
(14,562 (Addendum))
A.R.C. Technical Report

PUBLISHED BY HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, LONDON, W.C.2. 423 Oxford Street, LONDON, W.1
P.O Box 569, LONDON, S.E.1
13a Castle Street, EDINBURGH, 2 | 1 St Andrew's Crescent, CARDIFF
39 King Street, MANCHESTER, 2 | Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 | 80 Chichester Street, BELFAST
or from any Bookseller

1953

Price 1s. 6d. net

PRINTED IN GREAT BRITAIN

S.O. Code No. 23-9007-6