

PRINCIPLES OF REFRIGERATION

List of Contents

	<i>Para.</i>		<i>Para.</i>
Introduction	1	Pressure and Boiling Point	15
Principle	3	Refrigerants	17
Heat Transfer	5	Methyl Chloride	22
Heat and Temperature	6	Freon 12	24
Superheated Vapour	11	First Aid Treatment	25
Condensation	12	Use of Refrigerant	27
Heat Intake and Output... ..	13		

List of Illustrations

	<i>Fig.</i>		<i>Fig.</i>
Common Refrigerator	1	Freon (F12) Pressure-Temperature Table	6
Heat Transfer	2	Freon (F12) Pressure-Temperature Graph	7
Temperature	3		
Condensation	4		
Pressure Effect	5		

Introduction

1. Heat has always been essential to mankind, but the absence of heat, i.e. "cold", has only during latter years become the important aspect of engineering known as **refrigeration**. Refrigeration means cooling or keeping things cold by artificial means.

2. An application of refrigeration with which probably everyone is familiar is the preservation of foodstuffs. Additional aspects with which the general mechanic and fitter have to deal are in connection with ground equipment. This is provided for a number of purposes which include maintaining cool conditions in aircraft and ground stations for aircrew, groundcrew, and also for sensitive equipment.

Principle

3. The general principle of refrigeration is that heat transfers readily from a hot object to a cooler one. Thus if a cold object is placed in a warm room, the room will become cooler. If the cold object can be kept cold (i.e. the heat it acquires is dispersed), then the cooling of the room is continuous and this is the basis of a refrigerator (Fig. 1).

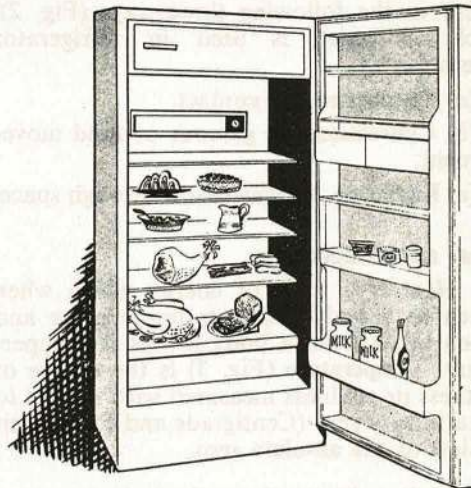
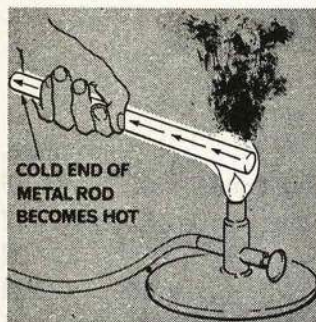


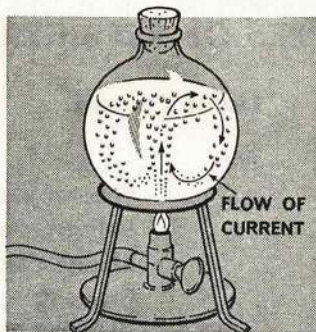
Fig. 1. COMMON REFRIGERATOR

4. Thus a refrigerator is a device which removes heat from substances so as to make them cold. But heat, because it is a form of energy, cannot be destroyed; thus, such heat must be deposited elsewhere. In cooling a substance below the temperature of its

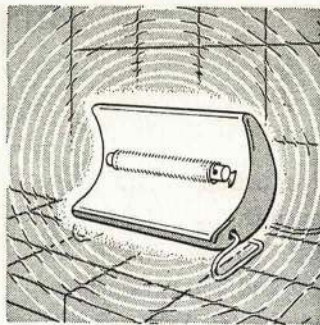
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CONDUCTION



CONVECTION



RADIATION

Fig. 2. HEAT TRANSFER

surroundings, heat is transferred from the substance to the surroundings, i.e. the reverse of the natural flow of heat. Thus a refrigerator can be likened to a heat pump. There are several ways of pumping heat, the most commonly used method being termed “**vapour compression**”. Another method is the “**absorption**” system.

Heat Transfer

5. As stated previously the natural flow of heat is from high to low and transfer can occur in the following three ways (Fig. 2), each of which is used in refrigerator operation:

- (a) **Conduction.** By contact.
- (b) **Convection.** By gaseous or fluid movement.
- (c) **Radiation.** By wave form through space.

Heat and Temperature

6. **Heat** is a form of energy which when given to a body raises its temperature and when taken from a body lowers its temperature. **Temperature** (Fig. 3) is the degree of hotness or coldness measured with respect to an arbitrary zero (Centigrade and Fahrenheit scales) or the **absolute zero**.

7. **Matter.** Matter in a physical sense may be in the form of a solid, liquid or gas, depending upon the temperature and, within certain limits, on the pressure to which it is subjected. Substances are solid at the coldest temperatures and pass through a liquid state to vapourize at higher temperatures. The temperatures at which solids change to liquids and liquids to gases or vapours are known as the **melting** and **boiling points** respectively, and they vary with different

substances. The change from liquid to gas and vice versa is made use of in refrigeration.

8. Any liquid is said to be **sub-cooled** when it is at a temperature lower than boiling point. If such a liquid is heated its temperature rises until it starts to boil, but it does not immediately boil away because a large amount of heat is required to change its state. Thus, although heat is being absorbed the temperature does not rise until the whole of the liquid has boiled away, i.e. the gas or vapour contains much more heat than the liquid but the heat is absorbed without a rise in temperature. There are, therefore, two types of heat:

(a) **Sensible Heat.** This is the heat which when added to or removed from a body causes a change in temperature as shown by a thermometer.

(b) **Latent Heat.** This is the heat which when added to or removed from a body causes a change of state from solid to liquid or from liquid to gas or vice versa without any variation of temperature as shown by a thermometer.

9. The temperature at which the latent heat is absorbed (and at which the liquid changes to gas) is dependent upon the pressure of the gas in which the process occurs. This temperature is commonly referred to as the **boiling point**, or in refrigeration engineering as the **saturation temperature**. Thus the saturation temperature is always associated with a specific pressure.

10. **Critical Temperature.** This is the temperature above which a given gas cannot be liquefied by an increase in pressure.

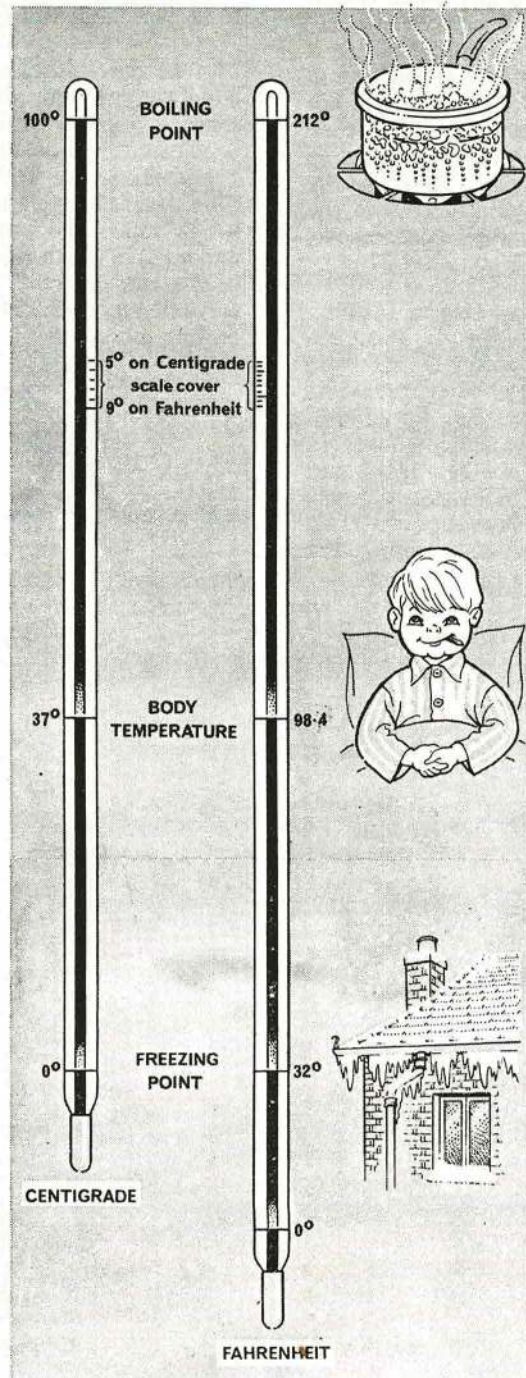


Fig. 3. TEMPERATURE

Superheated Vapour

11. Vapour is defined as a gas which is at a temperature lower than its critical temperature and can therefore be liquefied by a suitable increase in pressure. If heating is continued beyond the point when all the liquid has disappeared, the temperature of the vapour rises and continues to rise for as long as heat is being added. Thus vapour which is heated to a temperature above the boiling point is known as **superheated vapour**.

Condensation

12. **Condensation** is the process of forming a liquid from its vapour (Fig. 4). If superheated vapour is cooled gradually, as soon as the vapour cools to the temperature at which boiling took place then liquid will start to form and the temperature will remain constant until all the vapour has condensed back into liquid form. All the heat that was used to change the liquid into vapour (latent heat) has to be removed again to change the vapour back to liquid.

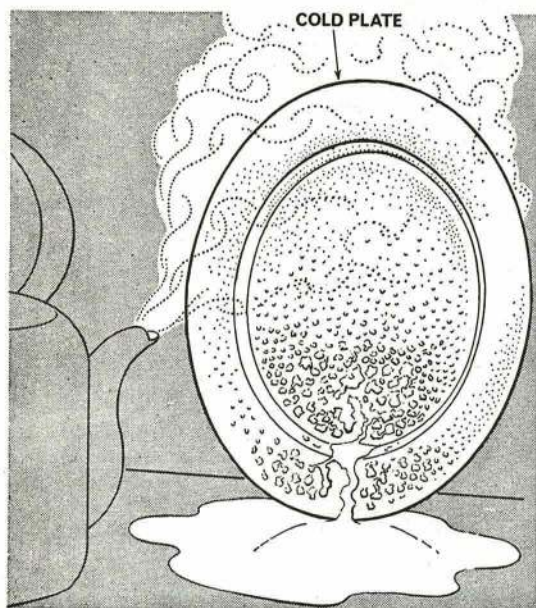


Fig. 4. CONDENSATION

Heat Intake and Output

13. An important factor in refrigeration is the ability of a liquid to absorb large quantities of heat without a rise in temperature during evaporation; this is used as a means of collecting heat in the evaporator (Chap. 2). Also, the ability of the vapour to dispose of

the same amount of heat when condensed back to a liquid is used to disperse the heat from the condenser (Chap. 2).

14. In view of the foregoing that boiling and condensation take place at the same temperature, a question which might now be posed is "how is it then that in a refrigerator the condenser is hot and the evaporator cold"? This state is brought about by the compressor which raises the pressure in the condenser and a valve which maintains a lower pressure in the evaporator. This introduces the need to understand the effect of pressure on the boiling point.

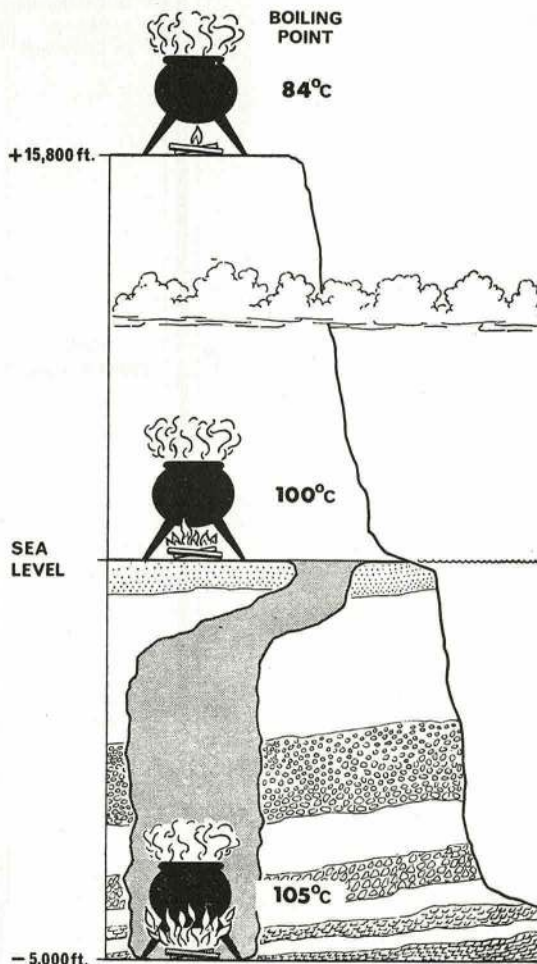


Fig. 5. PRESSURE EFFECT

Pressure and Boiling Point

15. Most of us know that at sea level the pressure of the atmosphere is 14 lb per sq. in.

and that at such a place a quantity of water will boil when its temperature is raised to 212°F. At the top of a mountain where the air is rarified and the atmospheric pressure is, of course, less than it is at sea level, water boils at a lower temperature than this. Down a deep mine where the atmospheric pressure is higher than it is at sea level, boiling will only occur when the temperature is raised above 212°F. (Fig. 5).

16. When water is under a pressure of 50 lb per sq. in. its temperature must be raised to 297°F. before it will boil, and at 500 lb per sq. in. it must be heated to 469°F. Conversely, if water is put in a vacuum chamber and the pressure reduced low enough it can be made to boil at ordinary room temperatures. Thus, the boiling point can be lowered by using a low pressure and raised by the use of a high pressure.

Refrigerants

17. A substance which is suitable for use as a working agent in a refrigerator is termed a **refrigerant**, an essential property of which is that it can be liquefied. Refrigerants must remain as vapours under the conditions within the refrigerator—they must never become gases. The essential difference between a vapour and a gas is that whereas the former can be liquefied by the application of pressure, a gas cannot be liquefied without the application of pressure plus the removal of heat. It is necessary therefore for a refrigerant to have a high critical pressure and temperature which are not reached in any part of the cycle.

Note: Although the term gas is scientifically incorrect it is used to a very wide extent in other publications, therefore, to avoid confusion it will also be used in this publication.

18. Such substances have very low saturation temperatures, for example ammonia, carbon dioxide, sulphur dioxide, methyl chloride, freon and others, and the selection of the refrigerant most suited to a particular refrigeration system depends largely on the boiling point. Two refrigerants which are used to a large extent in small units are methyl chloride which has a boiling point of -10°F. and freon 12 with a boiling point of -22°F. These are the atmospheric pressure boiling points and they vary with pressure as shown in the table below.

19. The behaviour of water as described in paragraphs 15 and 16 is equally applicable to refrigerants but their boiling points are not all the same. Freon 12 at 100 lb per sq. in. has a boiling point of 91°F. Thus at this pressure but colder than 91°F. it will be a liquid (sub-cooled), and if it is warmer than 91°F. it will be a gas (superheated).

20. If sub-cooled liquid at 100 lb per sq. in. is heated to 91°F. it will start to boil and the temperature will remain at 91°F. until all the liquid has evaporated. Whilst boiling continues there is a mixture of boiling liquid and gas, both being at 91°F. Similarly, if superheated gas at 100 lb per sq. in. is cooled to 91°F. it will start to condense and its temperature will remain at 91°F. until all the gas has condensed. Whilst condensation continues there is a mixture of condensing gas and liquid, both at 91°F.

21. Thus it is seen that the condition of the refrigerant at any pressure is dependent upon its temperature, for instance, if the pressure is 20 lb per sq. in. the temperature at which freon 12 liquid and gas can exist together is 18°F. and so on. The boiling points at various pressures for freon 12 are given in

Refrigerant	Boiling Point at Pressures of:		
	0 lb per sq. in. (Atmospheric)	20 lb per sq. in.	100 lb per sq. in.
Methyl Chloride	-10°F.	+30°F.	+98°F.
Freon	-22°F.	+18°F.	+91°F.

Figs. 6 and 7. At the present these Figs. only indicate the relationship between pressure and boiling (or condensing) temperatures but, as will be explained later in this section, they will also be found useful during servicing and fault diagnosis of refrigeration plant.

Methyl Chloride

22. Methyl chloride is produced from methyl alcohol and hydrochloric acid. It has the following characteristics:

- (a) Boiling point of -10°F . at atmospheric pressure.
- (b) It is almost colourless and has a faintly sweetish taste and smell.
- (c) The gas is 1.78 times as heavy as air.
- (d) It does not affect iron, steel, copper or brass, but corrodes aluminium and its alloys forming compounds that ignite or explode on contact with air.

23. **Precautions.** The following must be observed with methyl chloride:

- (a) It must not be inhaled because it causes unconsciousness.
- (b) It must not be used in any system having components made of aluminium or aluminium alloy.

Freon 12

24. Freon 12 is also known by its trade name of methane arcton. It has the following characteristics:

(a) Boiling point of -22°F . at atmospheric pressure.

(b) It is colourless and transparent in both its liquid and gaseous states, and smells faintly of coal gas.

(c) The gas is 4.26 times as heavy as air.

(d) In gaseous form it is non-irritating to the nose, eyes, throat and lungs.

(e) It has no corrosive effect on iron, steel, copper, brass, aluminium, lead or solder.

First Aid Treatment

25. Refrigerant in the eye will cause freezing of the eye moisture. In the event of such a mishap the eye should be treated as follows:

- (a) Avoid rubbing the eye.
- (b) Introduce drops of sterile mineral oil into the eye.
- (c) Should irritation continue, wash the eye with either a weak solution of boracic acid or a 2 per cent solution of salt.

26. In the event of liquid refrigerant coming into contact with the skin, treat the affected area as for frostbite by covering it completely for warmth.

IN BOTH INSTANCES THE MEDICAL OFFICER MUST BE CONTACTED IMMEDIATELY.

Temp. °F.	In. Vac. H.G.	Temp. °F.	Gauge Pressure lb/sq. in.	Temp. °F.	Gauge Pressure lb/sq. in.	Temp. °F.	Gauge Pressure lb/sq. in.	Temp. °F.	Gauge Pressure lb/sq. in.
-40	10.95	-8	5.38	30	28.5	68	67.5	106	128.1
-38	9.91	-6	6.28	32	30.1	70	70.1	108	132.1
-36	8.87	-4	7.21	34	31.7	72	72.8	110	136.0
-34	7.80	-2	8.17	36	33.4	74	75.5	112	140.0
-32	6.66	0	9.17	38	35.2	76	78.3	114	144.2
-30	5.45	2	10.2	40	37.0	78	81.2	116	148.4
-28	4.23	4	11.3	42	38.0	80	84.0	118	152.7
-26	2.93	6	12.4	44	40.7	82	87.0	120	157.1
-24	1.63	8	13.5	46	42.6	84	90.1	122	161.5
-22	0.58	10	14.7	48	44.7	86	93.2	124	166.1
-20	0.24	12	15.9	50	46.7	88	94.4	126	170.7
		14	17.1	52	48.8	90	99.6	128	175.4
		16	18.4	54	50.9	92	103.0	130	180.2
		18	19.7	56	53.1	94	106.3	132	185.1
		20	21.0	58	55.4	96	109.8	134	190.1
-18	1.31	22	22.5	60	57.1	98	113.2		
-16	2.07	24	23.97	62	60.1	100	116.9		
-14	2.85	26	25.4	64	62.5	102	120.8		
-12	3.67	28	26.9	66	64.9	104	124.3		
-10	4.50								

Fig. 6. FREON (F12) PRESSURE—TEMPERATURE TABLE

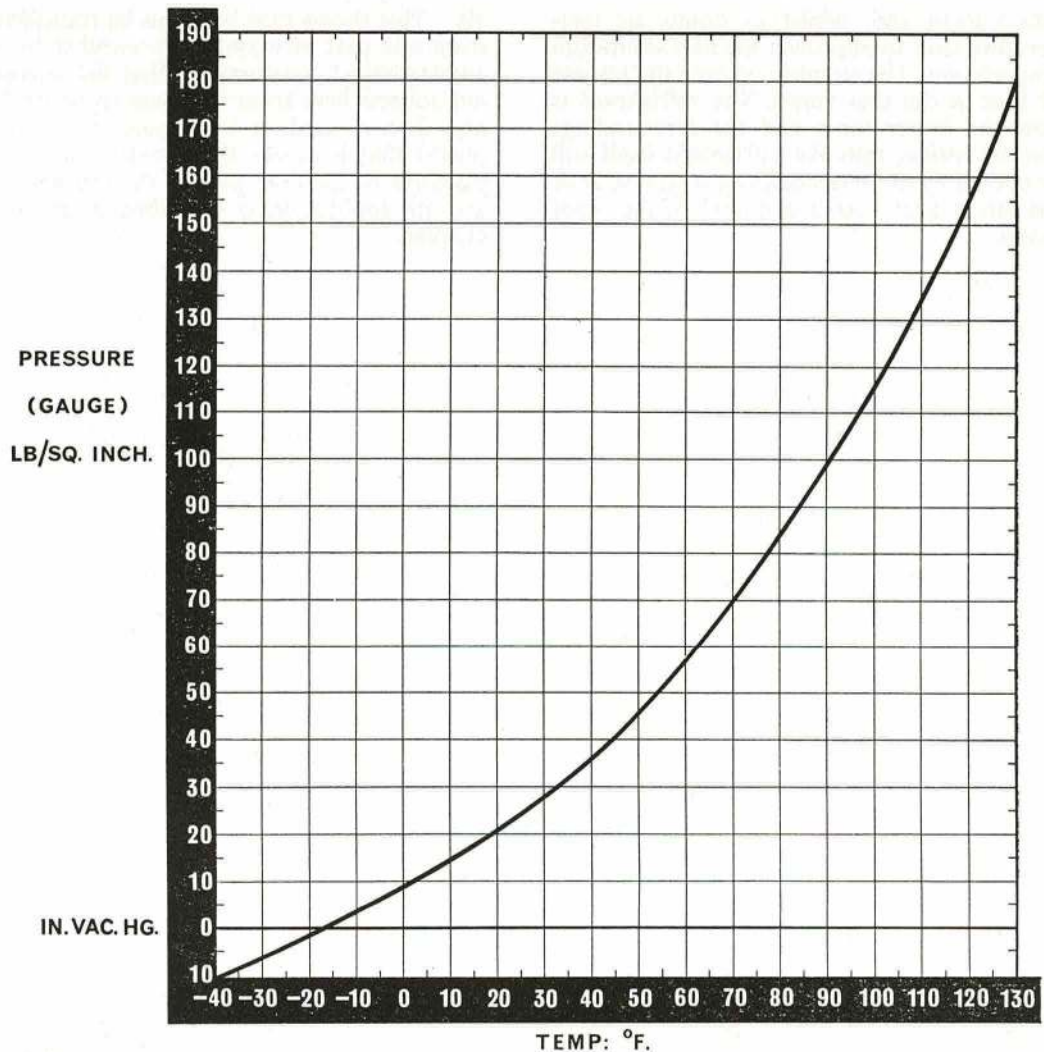


Fig. 7. FREON (F12) PRESSURE-TEMPERATURE GRAPH

Use of Refrigerant

27. If liquid refrigerant at its saturation temperature is introduced into a vessel situated in surroundings which are at a higher temperature than the liquid itself, then the liquid will change into a gas. The latent heat required to cause this change of state is taken from the surroundings which will thus be cooled.

28. If the refrigerant gas then passes into

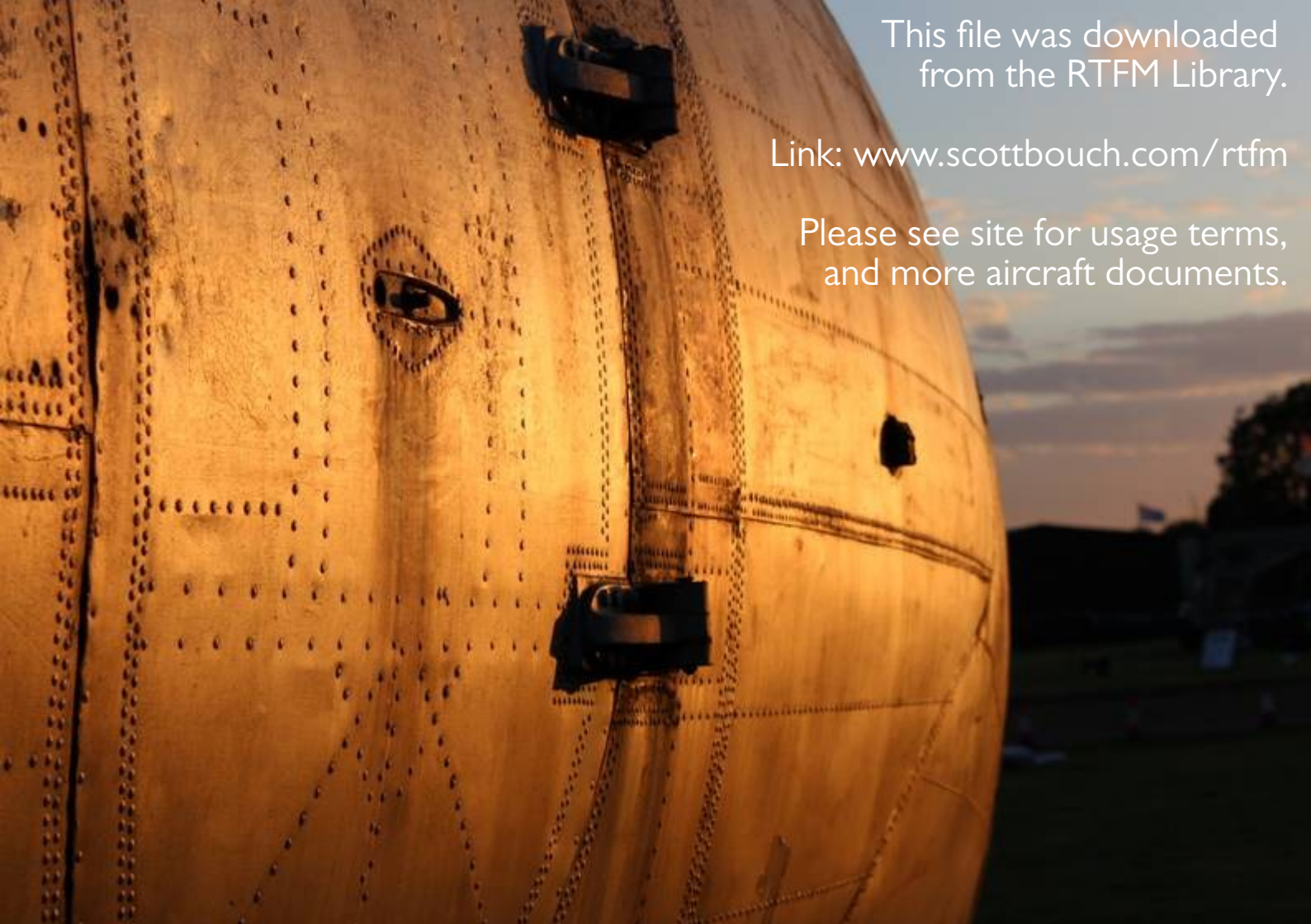
another vessel in which the pressure is increased quite considerably, the corresponding saturation temperature will also be increased. It will, in fact, be higher than the temperature of the gas passing into the vessel.

29. Because the refrigerant cannot stay in gaseous form at a temperature that is lower than the new boiling point it condenses into

(A.L. 24, Oct. 66)

liquid form and, whilst so doing, its temperature rises to approach the new saturation temperature. The situation is now the reverse of that in the first vessel. The refrigerant is now the hotter mass and the surroundings are the cooler, thus the refrigerant itself will be cooled by the surroundings, so giving back the latent heat that it acquired in the other vessel.

30. This shows that heat can be transferred from one part of a system to another by an adjustment of pressures, so that the refrigerant collects heat from the mass to be cooled and then discards it to a mass (the atmosphere) that is cooler than itself. This is the principle of the cold part of the refrigerator, and its application is described in the next chapter.



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