3.3: Temperature Scales II

We now know – by definition – the temperatures at the two fixed points on the Celsius and Kelvin scales. But what about temperatures between the fixed points? We could say that the temperature halfway between the melting point of ice and the boiling point of water is 50 ºC, or we could divide the temperature between the two fixed points into 100 equal intervals. But: What do we mean by "halfway" or by "equal intervals" in such a proposal? This leaves us rather stumped.

Here is one suggestion.

We could construct a glass capillary tube with a bulb at the bottom containing mercury, which also extends a short way up the capillary. We could note the length of the mercury column when the tube was immersed in melting ice and call the temperature 0 ºC, and again when it is in boiling water (100 ºC). We could then divide the length of the tube between these two marks into 100 equal intervals of length, and use that to define our temperature scale. But you may ask: How do we know that mercury expands (relative to glass) uniformly with temperature? Well, it expands uniformly, *by definition*, with temperature on the mercury-in-glass temperature scale. Indeed, we can *define* the temperature in the mercury-in-glass scale by

$$t=100\times\frac{l_t-l_0}{l_{100}-l_0}\ ^{\circ}\mathrm{C}. \tag{3.3.1}$$

(I am going to use the symbol T in these notes for temperature in *kelvin*. Here I am using t for temperature on the *Celsius* scale.)

If we place the thermometer (for such it is) in a bowl of warm water, and the length of the mercury column is halfway between l_0 and l_{100}, we could say that the temperature of the water in the bowl is, by definition, 50 ºC on the mercury-in-glass scale.

Now let us repeat the experiment with another type of thermometer, using some different property of matter which is also known to vary with temperature. We might choose, for example, to use the electrical resistance R of a length of platinum wire; or the thermoelectric potential difference V that appears when we heat the junction of two different metals; or the pressure P of some gas when it is heated up but kept at constant volume. We could try immersing each of these thermometers into melting ice and boiling water and we could interpolate linearly for intermediate temperatures. Thus, using the resistance of the platinum wire, we could define a platinum resistance temperature scale by

$$t=100\times\frac{R_f-R_0}{R_{100}-R_0}\ ^{\circ}\mathrm{C}. \tag{3.3.2}$$

Or we could define a thermoelectric temperature scale by

$$t=100\times\frac{V_t-V_0}{V_{100}-V_0}\ ^{\circ}\mathrm{C}. \tag{3.3.3}$$

Or we could define a constant volume gas temperature scale by

$$t=100\times\frac{P_t-P_0}{P_{100}-P_0}\ ^{\circ}\mathrm{C}. \tag{3.3.4}$$

But what assurance do we have that all of these temperature scales are the same? What assurance do we have that the resistance of platinum increases linearly on the temperature scale defined by the mercury-in-glass thermometer? What assurance do we have that, when we immerse all of these thermometers in the water that registered 50 ºC for the mercury-in-glass thermometer, they will all register 50 ºC?

The answer is that we have no such assurance.

What we need to do is either choose one particular phenomenon quite arbitrarily to use for our standard temperature scale, or somehow define an *absolute* temperature scale which is absolute in the sense that it is defined independently of the properties of any particular substance. It turns out that it is possible to do the latter, and to define a temperature scale that is absolute and independent of the properties if any particular substance by means of an idealized theoretical concept called a **Carnot Heat Engine**. This imaginary engine uses as its operating medium an equally imaginary substance called an *ideal gas*, and indeed the temperature indicated by a constant volume gas thermometer is identical to the absolute temperature defined by a Carnot engine – provided that the gas used is an ideal gas! The best that can be said for real gases is that, at low pressures, they behave very much like an ideal gas; and indeed if you somehow extrapolate the behaviour or a gas to its behaviour at zero pressure (when there isn't any gas at all!), it would behave exactly like a real gas.

Until we have discussed what are meant by a real gas and by a Carnot engine, all this has served to do is to underline what we said in the Introduction to this chapter – namely that there are a number of relatively easy concepts in thermodynamics, but temperature is not one of them.

If we do eventually understand what a Carnot engine is and we can construct in our minds a definition of what is meant by an absolute temperature scale, there will remain the problem of reproducing such a scale in practice. That is the purpose of the International Temperature Scale 1990 (ITS90). On this scale a number of fixed points, such as

- the triple point of hydrogen
- the triple point of neon
- the triple point of water
- the freezing point of zinc
- the freezing point of silver
- the freezing point of gold

etc.,

are assigned certain values. In the cases of the six points listed, these values are

- 13.8033
- 24.5561
- 273.16
- 692.677
- 1234.93
- 1337.33

kelvin respectively.

A number of standard instruments are to be used in different temperature ranges, with defined interpolation formulas for temperatures between the fixed points. A complete description of ITS90 would be rather lengthy (see, for example, http://www.omega.com/techref/intltemp.html), but its purpose is to reproduce as precisely as practically possible the absolute temperature scale as defined by the Carnot engine.
