Unit 9

Answers: Heat and Temperature

Quick checks

1 c Every body above absolute zero has thermal energy, and the pan of water has more (more molecules). But both are at 20 °C, so **no heat flows**: heat needs a difference in temperature, not a difference in thermal energy.

2 a Heat flows from the higher **temperature** to the lower, whatever the amounts of thermal energy. The nail is far hotter, so it loses heat and cools, and the water gains that heat and warms (very slightly, since there is so much of it).

3 c Temperature is the **average** per molecule. Thermal energy is the **total** kinetic energy of all the molecules, and internal energy adds their potential energy too; both grow with the amount of substance, while temperature does not. Heat is energy in transfer, not something the body has.

4 c In a metal, hotter atoms vibrate more and get in the electrons' way, so the resistance rises. In a semiconductor, heat frees many more charge carriers, which outweighs that, so the resistance falls. A thermistor in a digital thermometer uses this.

5 b Equilibrium means equal temperatures. Their thermal energies are equal only if the blocks are identical. And energy keeps passing between them, at equal rates both ways, so there is no **net** flow.

6 c The thermometer (C) was in equilibrium with A and with B at the same reading, so by the zeroth law A and B are in equilibrium with each other: same temperature, no net heat flow. Masses don't matter.

7 c A change: $\Delta F = \frac{9}{5}\Delta C = 1.8 \times 25 = 45$ °F. 77 °F is what 25 °C **is** on the Fahrenheit scale (adding 32), which answers a different question: what a temperature is, not how much it changed.

8 c Thermal equilibrium means no net heat flow, which happens exactly when the **temperatures** are equal. The bodies can be of different materials (different specific heat capacities and conductivities) and hold different amounts of thermal energy.

9 c $K = C + 273.15$, so the Kelvin number is always 273.15 more than the Celsius one: they can never be equal. Kelvin and Fahrenheit agree at 574.59; Fahrenheit and Celsius at −40; Réaumur and Celsius at 0 (both scales start at the ice point).
Some books give "Réaumur and Rankine" as the last option. That pair can never agree either (only at −491.67 °C, below absolute zero), so it is replaced here.

10 a For the same volume, a cylinder has more surface than a sphere (a sphere has the least surface of any shape), and its mercury is never far from the glass. So heat flows in and out of a cylindrical bulb faster.

11 **b** $F = 1.8C + 32$: at C = 0, F = +32, so it cuts the **positive y-axis** at 32 (Figure 9.7). It cuts the x-axis (F = 0) at C = −17.8, the **negative** x-axis, so it doesn't pass through the origin.

12 **c** Put F = 3C in $F = \frac{9}{5}C + 32$: $3C = 1.8C + 32 \Rightarrow 1.2C = 32 \Rightarrow C = 26.7$ °C, so F = 3 × 26.7 = **80 °F**. (80/3 °C, not °F, is the same temperature on the Celsius scale.)

13 **a** $\theta = \dfrac{0.040}{0.160} \times 100 = 25$ °C.

14 **d** $F = \frac{9}{5} \times 15 + 32 = 27 + 32 = 59$ °F. (27 °F forgets the 32: it is the size of a 15 °C **change** in Fahrenheit degrees.)

15 **b** $\dfrac{\theta - L}{U - L} = \dfrac{C}{100}$: $\dfrac{40 - L}{60 - L} = \dfrac{50}{100}$, so $80 - 2L = 60 - L$ and $L = 20^\circ$.

16 **b** The same fraction of the way on both scales:

$$\frac{50 - 14}{74 - 14} = \frac{Y - 25}{120 - 25} \quad \Rightarrow \quad \frac{36}{60} = \frac{Y - 25}{95}$$

$Y - 25 = 0.6 \times 95 = 57$, so **Y = 82°**.

Some books give 85° as the answer; the working gives 82°, so the option has been corrected.

17 **c** A kelvin is the same size as a Celsius degree, so a **change** of 27 °C is a change of 27 K. (300 K is the temperature 27 °C, not a change of 27 degrees.)

11.

a. Temperature is meant to be the one number that tells us whether heat will flow between two bodies: equal temperatures, no net flow. Suppose the law failed: A and B in equilibrium (no heat flow), B and C in equilibrium, but heat **did** flow between A and C when they touched. Then we could not give A, B and C numbers that say whether heat will flow: A and B would need the same number, B and C the same number, so A and C the same number too, yet heat flows between them. And a thermometer (B) that reads the same in A and in C would tell us nothing about whether A and C are in equilibrium. Because the law holds, "in thermal equilibrium with" sorts bodies into groups with one temperature each, and temperature means something.

b. **Absolute zero** is the lowest possible temperature, 0 K = −273.15 °C, at which the random motion of the molecules has its least possible energy (in the classical picture, the molecules' kinetic energy is zero). It is the zero of the Kelvin (absolute) scale, and a gas's pressure at constant volume, extended back, would fall to zero there.

c. A kelvin is the same size as a Celsius degree, so the change is $50.0 - 30.0 =$ **20.0 K**. (Or: 303.15 K to 323.15 K, a change of 20.0 K.)

12. a. Two bodies in thermal contact are in **thermal equilibrium** when there is no net flow of heat between them, which happens when they are at the same temperature. Energy still passes between them, but at equal rates in both directions.

b. Start from $\frac{C}{5} = \frac{F-32}{9}$, so $9C = 5F - 160$. Add 360 to both sides: $9C + 360 = 5F + 200$, that is $9(C+40) = 5(F+40)$. Dividing by 9:

$$C + 40 = \frac{5}{9}(F + 40)$$

(A neat way to convert: add 40, multiply by 5/9 or 9/5, subtract 40.)

c. $\frac{\theta - L}{U - L} = \frac{C}{100}$: $\frac{40-10}{80-10} = \frac{C}{100}$, so $C = \frac{30}{70} \times 100 = 42.9\ °\text{C} \approx$ **43 °C**.

13. a. On every scale, a reading is the same fraction of the way from the lower fixed point to the upper fixed point. So write that fraction for each scale and set them equal:

$$\frac{-}{-}$$

For Celsius, Fahrenheit and Kelvin this gives $\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$. Put in the known reading and solve for the other. Example: 25 °C is $F = \frac{9}{5} \times 25 + 32 = 77$ °F and $K = 25 + 273 = 298$ K.

b. Changes compare by the sizes of the degrees: $\Delta C = \Delta K = \frac{5}{9}\Delta F$. A rise of 10 °F is $\frac{5}{9} \times 10 = 5.6$ K, while B rose by 10 K. So **beaker B** is now at the higher temperature, by about 4.4 K. A kelvin is a bigger step than a Fahrenheit degree (1 K = 1.8 °F).

14. A change of temperature: $\Delta F = \frac{9}{5}\Delta C = \frac{9}{5} \times 45 =$ **81 °F**.

15. $$\frac{\theta - L}{U - L} = \frac{C}{100} \quad \Rightarrow \quad \frac{20-2}{98-2} = \frac{C}{100} \quad \Rightarrow \quad C = \frac{18}{96} \times 100 = \approx 18.8$$

Its 96 steps are each a little bigger than a Celsius degree, so above its ice point it reads slightly high: 20° on it is 18.75 °C.

16. Absolute zero is 0 K. On the Celsius scale, $C = K - 273.15 =$ **−273.15 °C** (−273 °C to three figures).

On the Fahrenheit scale, $F = \frac{9}{5}C + 32 = \frac{9}{5} \times (-273.15) + 32 = -491.67 + 32 =$ **−459.67 °F** (about −460 °F).

17. $F = \frac{9}{5} \times 40 + 32 = 72 + 32 =$ **104 °F**, a high fever (normal is about 98.6 °F, 37 °C).

18. These are changes, so no 32 or 273 comes in.

a. $\Delta F = \frac{9}{5}\Delta K = 1.8 \times 5 =$ a drop of **9 °F**.

b. $\Delta C = \Delta K =$ a drop of **5 °C**.