# Physics at Work Book 1

## Checkpoint, Practice and Revision answers

New Senior Secondary Physics at Work, Second Edition: Heat and Gases.

All 26 Checkpoints, all 11 Practice sections and all 152 numbered Revision questions across Chapters 1-5, including conventional, experiment and Physics in article questions. Original question numbering and subpart labels are retained.

Arranged in textbook order by chapter and subsection. Each chapter ends with its Revision exercise answers.

Independently worked solutions, not the publisher’s official marking scheme. Approximate graph readings and reasonable rounding are indicated. Unless otherwise stated, calculations neglect heat loss and container heat capacity. Water has c = 4200 J $kg^{-1}$ $°C^{-1}$; use Kelvin temperatures and absolute pressures in gas-law ratios.

Separate Self test, Example and Exam link sections are outside the requested coverage.

# Contents


**Chapter 1 - Temperature and Thermometers** 3

1.1 Temperature and the temperature scale . . . 3

1.2 Thermometers . . . 3

Revision exercise 1 . . . 3

**Chapter 2 - Heat and Internal Energy** 6

2.1 Internal energy . . . 6

2.2 Specific heat capacity . . . 6

Revision exercise 2 . . . 7

**Chapter 3 - Change of State** 11

3.1 Latent heat . . . 11

3.2 Evaporation . . . 12

Revision exercise 3 . . . 13

**Chapter 4 - Transfer Processes** 17

4.1 Conduction . . . 17

4.2 Convection . . . 17

4.3 Radiation . . . 18

Revision exercise 4 . . . 19

**Chapter 5 - Gases** 22

5.1 The gas laws . . . 22

5.2 The kinetic theory of gases . . . 23

Revision exercise 5 . . . 24

# Chapter 1 - Temperature and Thermometers

## 1.1 Temperature and the temperature scale

### Checkpoint 1 (p.6)

1. A: steam point and ice point.

2. C: other temperature scales exist, including Kelvin and Fahrenheit.

### Practice 1.1 (p.6)

1. C: body temperature is neither fixed nor readily reproducible.

2. (a) Lower: 0 °C; upper: 100 °C. (b) Use pure melting ice and steam immediately above pure boiling water, both at normal atmospheric pressure.

3. II, IV, V, I, III: freezer < melting ice < normal human body < boiling water < 200 °C.

4. (a) Temperature measures the degree of hotness of an object. (b) The two points are reproducible and have definite temperatures under specified conditions. (c) Divide the interval from ice point to steam point into 1000 equal divisions, or each 1 °C division into ten equal parts. (d) Incomplete: steam can have various temperatures. Steam point is the temperature of steam over pure boiling water at normal atmospheric pressure.

## 1.2 Thermometers

### Checkpoint 2 (p.13)

1. (a) 15 cm. (b) 80 °C. The plotted relation is approximately L = 3 + 0.20T, with L in cm and T in °C.

### Practice 1.2 (p.14)

1. B: direct heating with a Bunsen flame is not a calibration step.

2. C: infra-red thermometer.

3. B: X and Z change with temperature; Y does not.

4. (a) Electrical resistance of the thermistor. (b) Its resistance decreases as temperature increases. Measure its resistance and convert it to temperature using its calibration.

5. T = (80 - 35)/(120 - 35) × 100 = 52.9 °C.

6. (a-b) Any three suitable examples: liquid-in-glass - liquid volume; infra-red - intensity of emitted infra-red radiation; thermistor - electrical resistance; liquid crystal - colour.

7. (a) T = (15.6 - 4.2)/(18.4 - 4.2) × 100 = 80.3 °C. (b) L = 4.2 + 0.30(18.4 - 4.2) = 8.46 cm.

8. (a) Straight line through (T,L) = (0,5) and (100,25): L = 5 + 0.20T. Label temperature / °C horizontally and column length / cm vertically. (b) 15 cm. (c) (21 - 5)/0.20 = 80 °C.

## Revision exercise 1

Printed textbook pages 16-19. All 20 numbered questions, including experiments and Physics in article.

### Concept traps and multiple choice

1. False. The symbol is °C, not C°.

2. False. Use pure melting ice at normal atmospheric pressure. Pure ice alone may be below 0 °C.

3. B: (1) and (3), 0 °C and ice point.

4. D: all three can vary reproducibly with temperature.

5. A: only (2). At 0 °C, $T_F$ = 32 °F; at 100 °C, $T_F$ = 212 °F; a 1 °C change equals a 1.8 °F change.

6. C: R = 25 + (80 - 25) × 40/100 = 47 units.

7. C: mass does not ordinarily change with temperature for a closed object.

8. C: true temperature = (40 - 10)/(90 - 10) × 100 = 37.5 °C.

9. D: (2) and (3) have resistance that changes with temperature; (1) does not.

## Conventional questions

10. x = (12.0 - 3.7)/(24.6 - 3.7) × 100 = 39.7 °C.

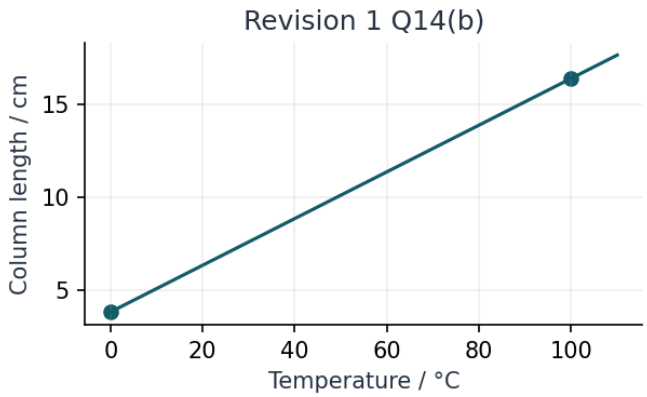
11. L = 6 + [(21 - 6)/80]T. (a) At 37 °C, L = 12.94 cm. (b) At 100 °C, L = 24.75 cm.

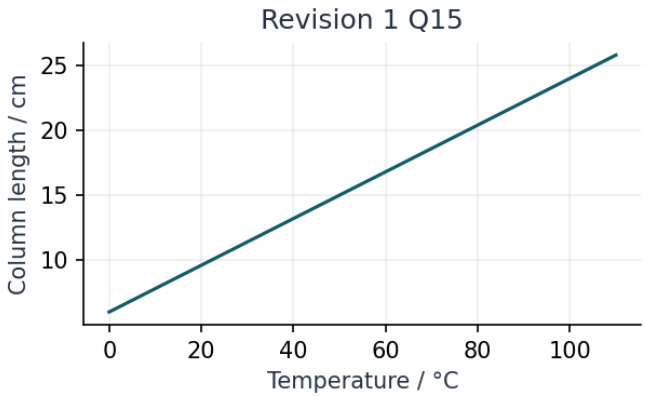
12. Define the lower fixed point as the temperature of pure melting ice at normal atmospheric pressure, 0 °C. Define the upper fixed point as the temperature of steam over pure boiling water at normal atmospheric pressure, 100 °C. Divide the interval into 100 equal temperature divisions, each of 1 °C.

13. (a) T = (7.7 - 3.2)/(18.2 - 3.2) × 100 = 30 °C. (b) L = 3.2 + (18.2 - 3.2) × 65/100 = 12.95 cm.

14. (a) T = (8.8 - 3.8)/(16.4 - 3.8) × 100 = 39.7 °C. (b) L = 3.8 + 0.126T, L in cm and T in °C. Sketch a straight line through (0,3.8) and (100,16.4). (c) Mercury is toxic; leakage can contaminate people and the environment, so it needs appropriate disposal.

15. From the line, L ≈ 6 + 0.18T. (a) T ≈ (16 - 6)/0.18 = 55.6 °C, approximately 56 °C. (b) L ≈ 6 - 1.8 = 4.2 cm. (c) Slope ≈ 0.18 cm $°C^{-1}$. (d) L ≈ 6 + 0.18T, or T ≈ (L - 6)/0.18. Small differences from graphical readings are acceptable.



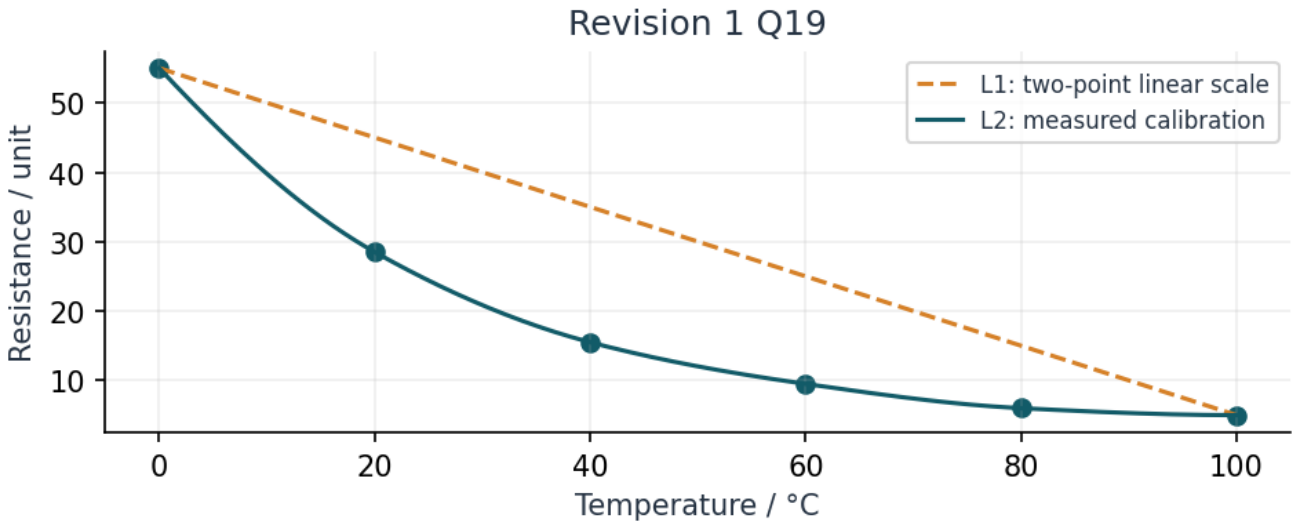

16. (a) The bonded metals expand by different amounts, causing the strip to bend and rotate a pointer. A strip of one uniformly heated metal expands without this differential bending. (b) Zinc: metal A lies on the longer, outer side of the bend and zinc expands more than iron when heated.

17. (a) Copper and X: their thermal expansions differ most, giving the greatest bending per degree. (b) X in a resistance thermometer: its highest melting point permits the highest operating temperatures. If a bimetallic rotary design is required, choose iron and X to avoid copper's lower melting point, but its upper limit is then constrained by iron.

18. (a) Any two: approximately uniform expansion over its useful range; quick response; high boiling point permitting high-temperature measurements; visible shiny thread that does not wet clean glass. (b)(i) The graph gives V(0) ≈ 0.0735 $cm^3$ and V(100) ≈ 0.0748 $cm^3$, so ΔV ≈ 0.0013 $cm^3$. (ii) A = 0.01 $mm^2$ = 0.0001 $cm^2$. ΔL = ΔV/A ≈ 13 cm; final length ≈ 3.6 + 13 = 16.6 cm. Approximate graph readings apply. (c) Disagree with a uniformly spaced two-point calibration: water's expansion is not uniform, especially between 0 and 4 °C, and it freezes/boils at the intended end points. It could only be used over a restricted suitable range with a proper nonuniform calibration.

## Experiment and article questions

19. (a) Draw L1 as a straight line from (T,R) = (0,55.0) to (100,5.0): R = 55.0 - 0.50T. (b)(i) Plot (0,55), (20,28.5), (40,15.5), (60,9.5), (80,6.0), (100,5.0), then draw a smooth decreasing curve L2 that becomes less steep. (ii) At the two end points the values agree; between them the measured resistances lie below L1. A thermistor is nonlinear, so a two-point linear scale is inaccurate.




20. (a) Colour changes with temperature; similar to a liquid-crystal thermometer. (b) A bimetallic strip bends with temperature and conducts electricity. It can directly make or break an electrical contact to switch a circuit at a chosen temperature.

# Chapter 2 - Heat and Internal Energy

## 2.1 Internal energy

### Checkpoint 1 (p.24)

1. True: the average molecular kinetic energy increases.

2. A: -300 °C is below absolute zero.

3. C: temperature measures average molecular kinetic energy, not total kinetic energy.

### Checkpoint 2 (p.28)

1. D: electrical energy supplied to the bulb.

2. A: heat.

3. B: $P = 540000/(5 \times 60) = 1800$ W.

4. $E = 2000 \times 30 \times 60 = 3.6 \times 10^6$ J = 1.0 kWh.

5. $t = 1.2/2.5 = 0.48$ h = 28.8 min = 1728 s.

### Practice 2.1 (p.28)

1. D: all three increase for a fixed body without a phase change.

2. C: heating and vigorous rubbing supply energy. A body with greater total internal energy need not be hotter.

3. B: the soup loses internal energy.

4. A: only (3) must be correct; mass also affects total internal energy and total kinetic energy.

5. (a) $5 \times 0.5 = 2.5$ kWh. (b) $9.0 \times 10^6$ J.

6. At constant power, $t = (1100/600) \times 10 = 18.3$ min = 1100 s.

7. (a) Incorrect: internal energy also depends on mass, material and state. A small hot object can have less internal energy than a large cooler one. (b) Incorrect: net heat flows spontaneously from higher temperature to lower temperature.

## 2.2 Specific heat capacity

### Checkpoint 3 (p.32)

1. B: $C = 240000/80 = 3000$ J °C$^{-1}$.

2. A: $T = 30 + 500000/10000 = 80$ °C.

### Checkpoint 4 (p.38)

1. D: the block, thermometer and polystyrene tile all receive some energy.

2. $C = mc = 5 \times 480 = 2400$ J °C$^{-1}$.

3. $Q = 0.5 \times 4200 \times (80 - 30) = 105000$ J = 105 kJ.

### Checkpoint 5 (p.44)

1. (a) Correct. (b) Incorrect: equal temperatures do not imply equal internal energies. (c) Correct, with negligible energy exchange with the surroundings.

2. $0.5c(T - 5) = 0.25c(20 - T)$, giving $T = 10$ °C.

### Practice 2.2 (pp.45-46)

1. D: c values for P,Q,R,S are 129, 234, 384.7 and 523 J $kg^{-1}$ $°C^{-1}$ respectively.

2. C: R receives the most energy in the same time.

3. D, on the textbook assumption of comparable energy-loss rates: P cools more slowly and has larger heat capacity; equal masses imply larger specific heat capacity. P is hotter at time T and has greater average molecular KE. The cooling curves alone would not establish (1)-(2) if heat-loss conditions differed.

4. C: inland city R has the least maritime moderation.

5. C: (1) and (3). A water-rich filling has high heat capacity, and water is an effective coolant.

6. A: (1) and (2) are both at 20 °C.

7. B: approximately 24 °C; water's heat capacity is much larger than copper's.

8. $Q = 1.75 \times 3770 \times (60 - 20) = 263900$ J ≈ 264 kJ.

9. Copper: $\Delta T = Q/(mc)$, and copper has the smaller specific heat capacity.

10. $T = 20 + (200 \times 300)/(0.5 \times 3500) = 54.3$ °C.

11. $t = 2 \times 1970 \times (90 - 25)/1500 = 171$ s ≈ 2.85 min.

12. Toast generally cools faster: its heat capacity is smaller than that of the water-rich soup, so a comparable energy loss produces a larger temperature decrease.

13. $0.5c(70 - 5) = 1 \times 4200 \times (90 - 70)$; $c = 2585$ J $kg^{-1}$ $°C^{-1}$ ≈ $2.58 \times 10^3$ J $kg^{-1}$ $°C^{-1}$.

14. $0.20 \times 4200(90 - T) = 0.080 \times 2000(T - 20)$; $T = 78.8$ °C.

15. $C = 50000/200 = 250$ J $°C^{-1}$.

16. $c = (56000 - 34000)/[0.20(47 - 23)] = 4583$ J $kg^{-1}$ $°C^{-1}$ ≈ $4.58 \times 10^3$ J $kg^{-1}$ $°C^{-1}$.

17. (a) $t = 130 \times 1000 \times 8/1500 = 693$ s ≈ 11.6 min. (b) $T = 28 + 750 \times 300/(130 \times 1000) = 29.7$ °C.

18. (a) From the hot metal to the cooler water. (b) $C(100 - 31.7) = 5 \times 4200(31.7 - 27)$; $C = 1445$ J $°C^{-1}$ ≈ $1.45 \times 10^3$ J $°C^{-1}$.

19. $T = (2 \times 80 + 5 \times 30)/7 = 44.3$ °C.

20. Water's high specific heat capacity allows it to absorb much energy with only a small temperature rise.

21. Water absorbs much of the supplied energy because of its high heat capacity, keeping the rubber relatively cool. The air-filled balloon's rubber heats up and weakens much more rapidly. Use $l_f(ice) = 3.34 \times 10^5$ J $kg^{-1}$ and $l_v(water) = 2.26 \times 10^6$ J $kg^{-1}$ except where the question asks you to calculate an experimental value.

## Revision exercise 2

Printed textbook pages 49-55. All 32 numbered questions. Use $c_{water} = 4200$ J $kg^{-1}$ $°C^{-1}$; neglect external heat exchange unless it is being discussed.

### Concept traps and multiple choice

1. False. Heat flows because of the temperature difference, not because the hot water necessarily has more total internal energy.

2. False. The arithmetic mean applies only when the two blocks have equal heat capacities and losses are negligible. Generally, T_final = (C1T1 + C2T2)/(C1 + C2).

3. B: kWh $°C^{-1}$ is energy divided by temperature change.

4. A: equal temperature means no net heat flow.

5. B: 2 × 480 × (100 - 35) = m × 4200 × (35 - 20), giving m = 0.990 kg.

6. A: only (3). A higher temperature does not establish greater heat capacity or greater total internal energy.

7. B: only (2), using the textbook model in which molecular KE is minimum at absolute zero.

8. B: (1) and (2). A substance's solid state need not be hotter than its gas state.

9. A: only (3) is incorrect. Absolute zero is approximately -273 °C.

10. C: higher temperature means higher average molecular KE for the same body.

11. A: only (2). Heat is energy being transferred; a body stores internal energy. Mass alone cannot compare different bodies' internal energies.

12. C: the block/thermometer may continue warming after the heater is switched off because of thermal lag. Observe the maximum stabilized temperature rather than taking the reading immediately. Oil improves contact, while insulation reduces loss.

13. B: actual c < (J2 - J1)/(mΔT), because some metered energy is lost to the surroundings rather than heating the block.

14. C: c = 400 × 60/[2(25 - 15)] = 1200 J $kg^{-1}$ $°C^{-1}$.

15. C: R has the smallest temperature-time slope, so the highest specific heat capacity for the same mass and power.

16. D: steam at 100 °C has the highest temperature and hence the greatest average molecular speed for the same substance.

17. A: (1) and (2). The steeper slope means lower heat capacity; equal material then implies less mass. Specific heat capacity alone cannot be inferred without the masses.

18. C: the common final temperature is above 35 °C because the initially hotter block has greater heat capacity.

## Conventional questions

19. (a) Q = 3 × 4200 × (15 - 12) = 37800 J. (b) Average power = 37800/300 = 126 W. (c) 576(T - 15) = 37800, giving T = 80.6 °C.

20. (a) Useful heating power P = 0.600 × 4200 × 60/90 = 1680 W. (b) Actual electrical input power is higher: energy also heats the kettle and is lost to the surroundings.

21. (a) T = (5 × 20 + 7 × 30)/(5 + 7) = 25.8 °C. (b) Unchanged: the same specific heat capacity multiplies both incoming streams and cancels from the energy balance.

22. (a) Total heat capacity = 0.800 × 4200 + 192 = 3552 J $°C^{-1}$. P = 3552 × (90 - 20)/300 = 828.8 W ≈ 829 W. (b) Extra energy = P × 60 = 49728 J. This heats the added noodles from 15 to 90 °C, so C_noodles = 49728/75 = 663 J $°C^{-1}$.

23. (a)(i) Copper loses 5 × 385(70 - T) = 1925(70 - T) J. (ii) Steel loses 2 × 450(90 - T) = 900(90 - T) J. (iii) Water gains 9 × 4200(T - 10) = 37800(T - 10) J. (b) 1925(70 - T) + 900(90 - T) = 37800(T - 10); T = 14.6 °C.

24. (a) Q = 0.300 × 4200 × (23 - 8) = 18900 J. (b) Average rate = 18900/300 = 63 W. (c) Smaller: polystyrene slows heat transfer into the cold water.

25. (a) 1 × 4200(25 - 18) = 0.6c(18 - 4); c = 3500 J $kg^{-1}$ $°C^{-1}$. (b) Water loses 29400 J of internal energy as energy flows to the colder shrimp; its temperature and average molecular KE decrease. (c) Total heat capacity = 4200 + 0.6 × 3500 = 6300 J $°C^{-1}$. t = 6300(100 - 18)/1500 = 344 s ≈ 5.74 min.

26. (a) Average molecular KE decreases as the water cools toward 4 °C; molecules move less vigorously. (b) On reaching 4 °C, water loses more internal energy because its specific heat capacity is larger: 67200 J for 1 kg of water versus approximately 7680 J for 1 kg of iron if c_iron = 480 J $kg^{-1}$ $°C^{-1}$. (c) Correct under comparable conditions: more water increases the effective heat capacity, so a given heat gain produces a smaller temperature rise after a power failure.

27. The soup and metal bowl reach a higher final temperature than the soup and ceramic bowl. Equal bowl masses but larger ceramic c mean larger ceramic heat capacity. More energy is needed to warm the ceramic bowl by a given amount, so the soup cools further. Algebraically T = (C_soup T_soup + C_bowl T_initial)/(C_soup + C_bowl).

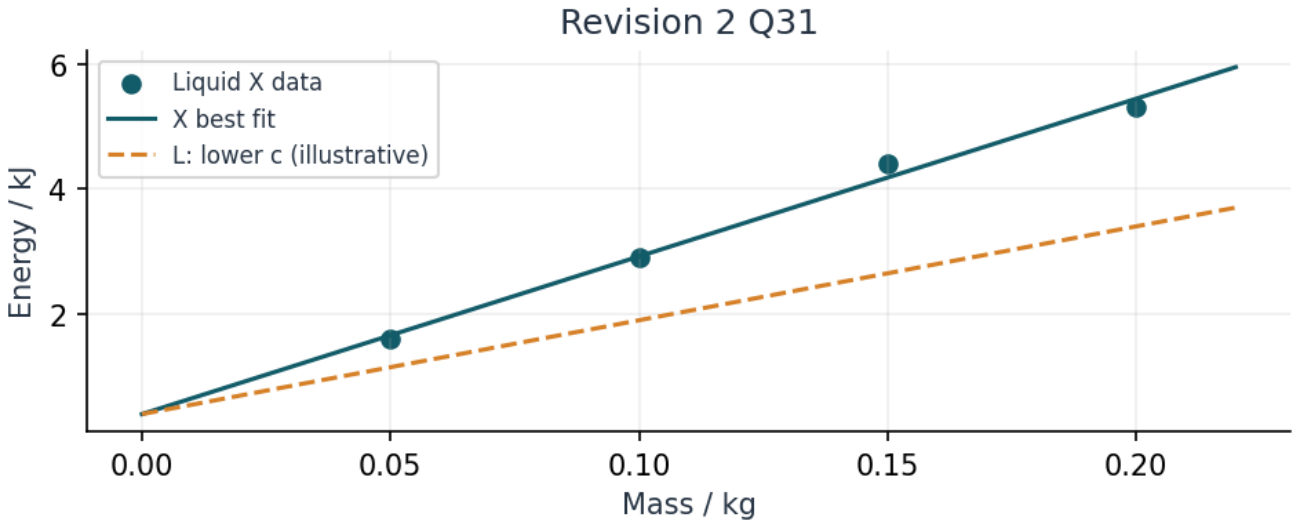
28. (a) Q = 0.45 × 4200 × (35 - 15) = 37800 J. (b)(i) Copper loses 37800 J. (ii) ΔT_copper = 37800/(0.12 × 390) = 807.7 °C. (iii) Initial copper temperature ≈ 35 + 807.7 = 843 °C. This estimates the flame temperature only if the copper first reaches thermal equilibrium with the flame and transfer losses are negligible.

## Experiment and article questions

29. (a) c = (106900 - 98500)/[1.20(35.0 - 28.5)] = 1077 J $kg^{-1}$ $°C^{-1}$. (b) Percentage error = (1077 - 900)/900 × 100% = 19.7%, high. (c) Safety: do not touch the hot block/heater; switch off before handling. Accuracy: improve insulation or place a little oil in the thermometer hole to improve thermal contact; allow for thermal lag when finding the final temperature.

30. (a) Measure a known mass m of water (or determine it from measured volume and density). Stir and record initial temperature T1. Heat it in the microwave for measured time t, then promptly stir and record final uniform temperature T2. Use P_useful ≈ mc_water(T2 - T1)/t; keep below boiling and use a microwave-safe container. (b) Some energy heats the container or is lost; the rated power may also be electrical input rather than useful absorbed power. (c) Measure 1 works: a smaller container heat capacity reduces unaccounted energy absorption. Measure 2 generally reduces container heating as a fraction of the total, but for a fixed heating time a larger mass gives smaller ΔT and a larger relative thermometer error. Choose a mass/time combination giving a readily measurable temperature rise.

31. (a) Insulation reduces energy exchange with the surroundings. (b)(i) Plot (m/kg,E/kJ) = (0.05,1.6), (0.10,2.9), (0.15,4.4), (0.20,5.3) and draw a best-fit straight line; do not join successive data points. An approximate fit is E(kJ) = 25.2m + 0.40. (ii) E = mcΔT + Q_apparatus, so slope = c × 10. c ≈ 25.2 × 1000/10 = 2520 J $kg^{-1}$ $°C^{-1}$. Graphical values around 2500-2600 are reasonable. (iii) Vertical intercept ≈ 0.40 kJ = 400 J. (iv) Draw L with a smaller slope but the same vertical intercept, because the apparatus still warms by 10 °C.




32. (a) Following the article's stated 30% decrease of the Celsius value: $T_{final} \approx 0.70 \times 75 = 52.5$ °C. $0.200 \times 4200(75 - 52.5) = C_{mug}(52.5 - 20)$, giving $C_{mug} \approx 582$ J °C$^{-1}$. The article's percentage is an empirical Celsius-temperature statement, not an absolute-temperature law. (b) At the same preheating temperature, a larger utensil of the same material has a larger heat capacity, so a given energy loss causes a smaller temperature decrease and it helps maintain food temperature longer, other heat-loss conditions being comparable.

# Chapter 3 - Change of State

## 3.1 Latent heat

### Checkpoint 1 (p.64)

1. D: latent heat is released during the constant-temperature stage QR. The graph does not tell us whether this is freezing or condensation.

2. D: two states coexist during QR.

### Checkpoint 2 (p.67)

1. Z: its constant-temperature melting section is highest.

2. Z: its melting plateau lasts longest, so for equal masses and equal heater powers its specific latent heat is greatest.

3. $Q = 0.7 \times 4200 \times 10 + 0.7 \times 334000 = 263200$ J ≈ 263 kJ.

4. $l_f = 107000/0.3 = 3.57 \times 10^5$ J $kg^{-1}$, using the supplied experimental data.

### Checkpoint 3 (p.74)

1. Wrong: $mc\Delta T$ heats water to its boiling point; it does not vaporize it. Specific latent heat of vaporization requires the energy supplied during vaporization divided by the mass vaporized.

2. $Q = 1 \times 334000 + 1 \times 4200 \times 100 + 1 \times 2260000 = 3.014 \times 10^6$ J.

3. $t = 2 \times 2260000/1500 = 3013$ s ≈ 50.2 min.

### Checkpoint 4 (p.77)

1. Melting: (a) KE unchanged, (b) PE increases, (c) internal energy increases, (d) temperature unchanged. Heating liquid water: (a) KE increases, (b) PE approximately unchanged in the textbook model, (c) internal energy increases, (d) temperature increases. Boiling: (a) KE unchanged, (b) PE increases, (c) internal energy increases, (d) temperature unchanged.

### Practice 3.1 (pp.77-79)

1. C: average molecular kinetic energy remains constant during the phase change at fixed temperature.

2. A: molecular KE follows temperature and is constant during melting. Internal energy and molecular PE increase during the plateau.

3. A: energy left for boiling = $1000 \times 600 - 0.5 \times 4200 \times 80 = 432000$ J; mass = 432000/2260000 = 0.191 kg.

4. A: only (1). Q's shorter melting plateau means less latent heat absorbed. The masses are unspecified, so specific latent heats cannot be compared. The graph shows P starts melting earlier.

5. B: cotton wool reduces heat loss. A lid can retain condensate and invalidate the mass-loss measurement; a lower heater power increases the fractional heat loss.

6. (a) 65 °C, the freezing/melting point. (b) Incorrect: the substance releases latent heat while freezing. Molecular PE and internal energy decrease although temperature and average molecular KE remain constant.

7. (a) $Q = 10^8 \times 334000 = 3.34 \times 10^{13}$ J. (b) Include melting: $Q = 10^8(334000 + 4200 \times 4) = 3.508 \times 10^{13}$ J.

8. $t = 0.2[4200(100 - 10) + 2260000]/1200 = 440$ s ≈ 7.33 min.

9. Let m be steam mass. $m \times 2260000 = (1 - m) \times 4200 \times 100$. Steam = 0.157 kg; initial water = 0.843 kg.

10. (a) $0.3 \times 5300(25 - T) = 0.1 \times 334000 + 0.1 \times 4200T$; T = 3.16 °C. All ice melts because the Coke can release 39750 J on cooling to 0 °C, exceeding the 33400 J needed to melt the ice. (b) No heat exchange with the surroundings and negligible cup heat capacity; use water's specific heat capacity for melted ice. (c) Usually higher: the room and initially warm container supply additional energy to the cold mixture.

11. (a) Final temperature = 68 - 38 = 30 °C. $0.3c \times 38 = 0.1 \times 334000 + 0.1 \times 4200 \times 30$; $c = 4.04 \times 10^3$ J kg$^{-1}$ °C$^{-1}$. (b) $m = 0.3c(68 - 15)/(334000 + 4200 \times 15) = 0.162$ kg.

12. (a) $P = 0.3 \times 2260000/(5 \times 60) = 2260$ W = 2.26 kW. This is the useful heating power; actual input may be higher. (b) Average molecular KE remains constant; molecular PE increases.

13. Water bath: $T = (0.3 \times 50 + 1 \times 0)/1.3 = 11.5$ °C. Ice: cooling the water to 0 °C releases $0.3 \times 4200 \times 50 = 63000$ J, which melts only 63000/334000 = 0.189 kg of ice. Some ice remains and the final temperature is 0 °C. The ice cools it further.

14. $m(2060 \times 4 + 334000) = 0.25 \times 4200 \times 80$; m = 0.245 kg.

15. (a) $0.3 \times 4200(20 - 14) = 0.02l_f + 0.02 \times 4200 \times 14$; $l_f = 3.192 \times 10^5$ J kg$^{-1}$. (b) Lower than $3.34 \times 10^5$ J kg$^{-1}$ by about 4.4%. (c) Meltwater adhering to the ice is counted as ice but needs no latent heat, giving an underestimate. Dry the ice before adding it.

16. Suggested ticks for the illustrated methods (vaporization $l_v$ / fusion $l_f$ / specific heat capacity c):

16a. Temperature immediately after switching off: c only.

16b. Lid: c only; do not trap condensate in the mass-loss vaporization method or obstruct drainage from the ice funnel.

16c. Stirring: c only, to keep the measured water temperature uniform.

16d. Crushed material: $l_f$ only, to ensure good contact with the heater.

16e. Melting material: $l_f$ only, so the ice starts at 0 °C.

16f. Heating element fully immersed/surrounded: $l_v$, $l_f$ and c.

16g. Cotton-wool insulation: $l_v$ and c for the illustrated arrangements. Insulating an ice funnel can also reduce unwanted environmental melting if drainage is unobstructed, though the matched control is the main correction in this method.

16h. Short connecting wires: $l_v$, $l_f$ and c, to reduce unwanted wire heating where the meter includes that energy.

16i. Equal material quantities in experimental and control arrangements: $l_f$ only.

## 3.2 Evaporation

### Checkpoint 5 (p.84)

1. Longer; slows down.

2. B: boiling occurs at a definite boiling temperature at a given pressure; evaporation occurs over a range of temperatures.

3. C: evaporation carries energy away from the liquid.

4. Any two: temperature, exposed surface area, airflow, humidity or liquid type. Higher temperature, larger area, more airflow and lower humidity increase evaporation.

### Checkpoint 6 (p.85)

1. True: condensation releases latent heat.

2. $m = 5.2 \times 10^{19}/(2.26 \times 10^{6}) = 2.30 \times 10^{13}$ kg.

### Practice 3.2 (p.86)

1. A: folding reduces exposed surface area.

2. C: faster molecules preferentially escape, lowering the average KE of those remaining.

3. C: (1) and (3).

4. $Q = 1.5 \times 2.26 \times 10^{6} = 3.39 \times 10^{6}$ J.

5. Water remaining on the skin evaporates, taking energy from the body. Wind removes humid air and increases evaporation and cooling.

6. (a) Warm humid outside air contacts the cold lenses and water vapour condenses into droplets. (b) The bathroom's warm humid air contacts the cooler lenses and condenses.

7. (a) $Q = 0.5 \times 2.26 \times 10^{6} = 1.13 \times 10^{6}$ J. (b) $P = Q/3600 = 314$ W. (c) Any two factors listed in Checkpoint 5 Q4.

8. (a) $Q = 0.2 \times 2.26 \times 10^{6} = 452000$ J. (b) $\Delta T = 452000/(50 \times 3500) = 2.58$ °C.

9. Water vapour deposits as ice crystals on sufficiently cold surfaces below freezing. Water droplets already on the surfaces can also freeze; frost itself usually forms by direct vapour-to-ice deposition.

10. A's covering reduces the exposed water surface and traps humid air, slowing evaporation. Less water evaporates from A, so its final level is higher.

## Revision exercise 3

Printed textbook pages 89-97. All 38 numbered questions. Use $c_{water} = 4200$ J kg$^{-1}$ °C$^{-1}$, $l_f = 3.34 \times 10^{5}$ J kg$^{-1}$ and $l_v = 2.26 \times 10^{6}$ J kg$^{-1}$.

### Concept traps and multiple choice

1. True during mixing before thermal equilibrium: the water away from the ice can still be above 0 °C while the ice melts at its surface. An equilibrium mixture of pure ice and water is at 0 °C; a nonequilibrium mixture does not yet have one uniform temperature.

2. False. Evaporation rate depends mainly on exposed area, temperature, airflow, humidity and liquid type, not simply total quantity. Identical cylindrical containers present the same exposed area at comparable filling conditions.

3. B: (1) and (3). Covering the water and reducing temperature decrease evaporation.

4. A: only (3). Steam releases much latent heat on condensing; it can cause serious burns and does not help drying by increasing local humidity.

5. A: only (1), in the usual surroundings-supplied evaporative-cooling description. Evaporation can also draw on the liquid's own internal energy; it cools the liquid and is slower at high humidity.

6. B. At constant mass and heater power, c is inversely proportional to the sloping section's gradient. The solid section P is less steep than gas section T, so $c_{solid} > c_{gas}$. Q is melting at -10 °C; S is boiling at 80 °C and lasts longer than Q.

7. A: only (1). Solid and liquid coexist during QR; latent heat is released and internal energy falls. Average KE decreases on PQ and RS because temperature falls.

8. A: only (2). The energy-mass slope gives specific latent heat of vaporization. No temperature change or boiling temperature is provided.

9. D: all three. Both processes change molecular PE and internal energy and can take place below boiling point.

10. B: larger mass gives a slower temperature rise, the same transition temperature and a longer constant-temperature transition.

11. A: only (3). While boiling at constant pressure, temperature and average KE remain constant; soup mass and its total internal energy decrease as vapour escapes (neglecting composition changes).

12. B: only (2). At equilibrium with surroundings also at 0 °C there is no net heat removal to supply freezing's latent-heat loss.

13. C: 0 °C. The warm water can release 1 × 4200 × 20 = 84000 J, melting only 84000/334000 = 0.251 kg. Ice remains.

14. C: m_ice/m_steam = [2260000 + 4200(100 - 50)]/[334000 + 4200(50 - 0)] = 4.54 ≈ 4.5:1.

15. C: 1 × 4200(60 - 40) = 0.15l_f + 0.15 × 4200 × 40; l_f = 448000 J $kg^{-1}$ = 4.48 × $10^5$ J $kg^{-1}$. This is the experiment's uncorrected estimate.

16. D: the final temperature approaches 20 °C, the surrounding temperature. From Q to R the water loses heat; the ice absorbed latent heat during P to Q.

17. B: only (3). Evaporation also requires energy and can occur below room temperature.

18. B. Splashed water is mistakenly counted as vaporized mass, so l_estimated = E/Δm is too small.

19. A: the solid warms 60 °C in 2 min, so P/m = 800 × 60/(2 × 60) = 400 W $kg^{-1}$. Melting lasts 6 min; l_f = (P/m) × 360 = 144000 J $kg^{-1}$ = 144 kJ $kg^{-1}$.

## Conventional questions

20. (a) X is the melting point, 0 °C. (b) Y is room/surrounding temperature, approached after all ice melts. (c)(i) Before t1, average molecular KE increases as ice warms, while molecular PE is approximately unchanged in the textbook model. (ii) Between t1 and t2, PE increases during melting, while average KE and temperature remain constant.

21. (a) Q = 1.5[4200 × 30 + 334000 + 2060 × 5] = 705450 J ≈ 705 kJ. (b) Average rate = 705450/(5 × 3600) = 39.2 W.

22. (a) Q = 0.2[4200 × 30 + 334000] = 92000 J. (b) As sprayed water freezes, it releases latent heat and helps keep the fruit near 0 °C rather than dropping to the colder air temperature. Continued appropriate water application is needed while heat is being lost.

23. (a) P = (0.015/60) × 2260000 = 565 W. (b) Condensed mass = 0.60 × 0.015 × 4 = 0.036 kg; Q = 0.036 × 2260000 = 81360 J ≈ 81.4 kJ.

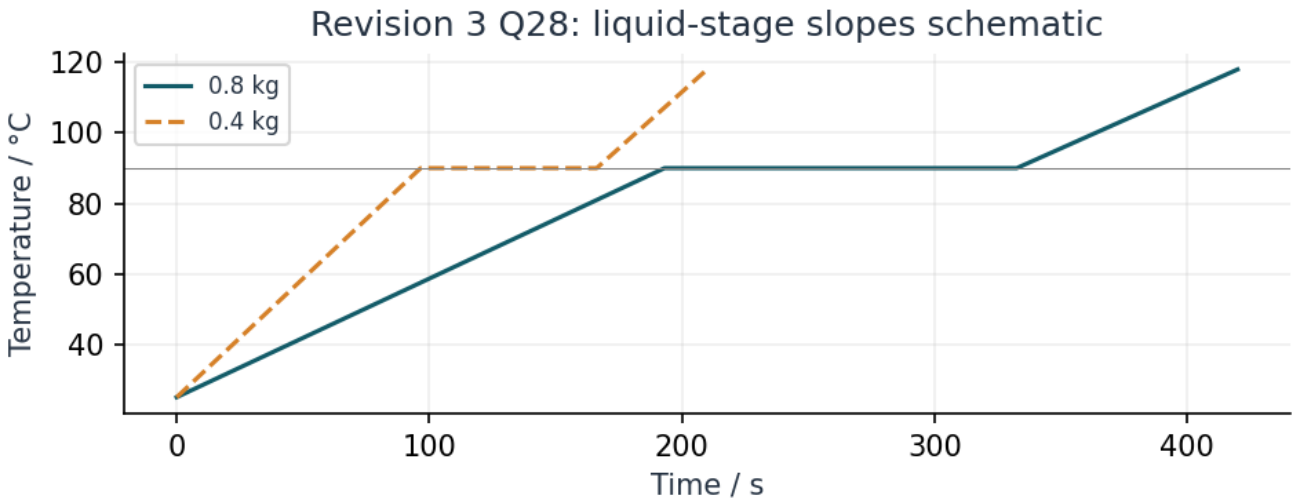
24. (a) ΔT = 334000/(70 × 1012) = 4.71 °C. (b) Melting snow absorbs latent heat and can cool the adjacent air if the energy comes from that air. The effect is plausible locally; a general air-temperature decrease is not inevitable because sunlight, ground heat and weather can also supply energy.

25. (a) Q = 0.5[4200(100 - 25) + 2260000] = 1.2875 × $10^6$ J ≈ 1.29 MJ. (b)(i) Larger total supplied energy for the pot arrangement. (ii) In addition to heating and vaporizing the water, energy heats the pot and lid. If comparing energy absorbed by the water alone at the same pressure, it is the same as in (a); the hole lets steam escape and prevents a sealed pressure-cooker interpretation.

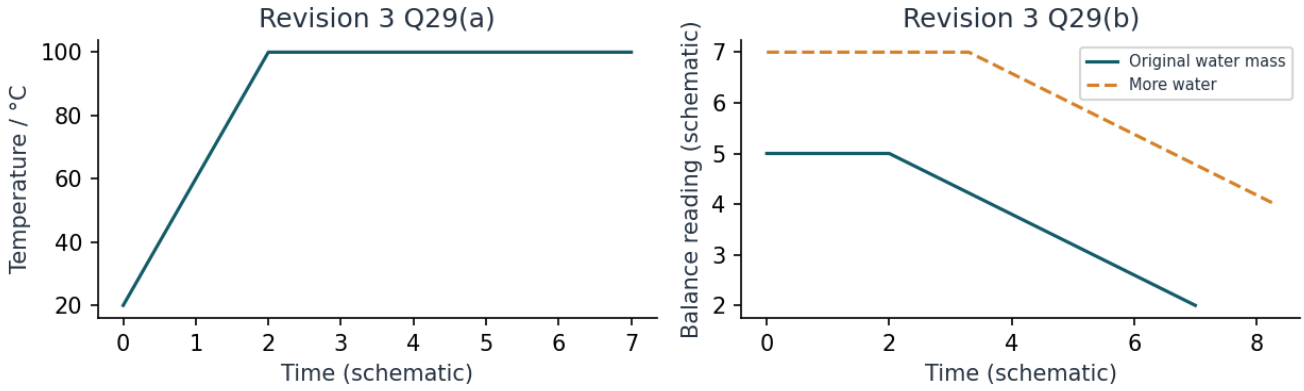
26. (a) l_est = Pt/Δm = 20 × 180/0.010 = 3.60 × $10^5$ J $kg^{-1}$. (b) Supplied energy = 3600 J; actual vaporization energy = 0.010 × 300000 = 3000 J. Energy lost = 600 J.

27. (a) Evaporation. (b) Rising vapour cools; on reaching saturation it condenses on particles into droplets. Droplets grow/coalesce and eventually fall as rain. (c) Condensation releases latent heat, warming the surrounding air relative to otherwise identical conditions without condensation.

28. (a)(i) Start of melting: t1 = 0.8 × 1300(90 - 25)/350 = 193 s. (ii) Additional melting time = 0.8 × 61000/350 = 139 s; melting finishes at t2 ≈ 333 s. (b) Draw a line from (0 s,25 °C) to (193 s,90 °C), then a horizontal plateau to (333 s,90 °C), followed by a rising line once all material is liquid (slope then depends on the liquid's c). (c) For half the mass, the same melting temperature, twice the temperature-rise gradient before melting, t1 ≈ 96.6 s and t2 ≈ 166 s; the plateau lasts 69.7 s.



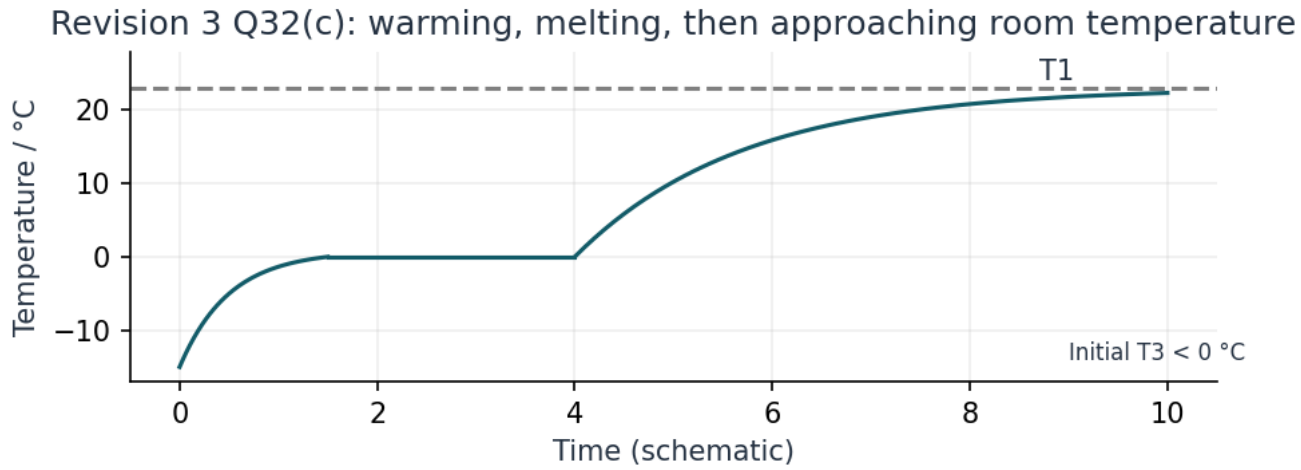

29. (a) Temperature rises from its initial value until boiling starts, then stays at the boiling point (100 °C at normal atmospheric pressure). The flat part of the balance curve is the warming stage; the falling-mass part is boiling. (b) More water gives a higher initial balance reading and a longer horizontal interval, because it takes longer to reach boiling. Once boiling begins, the mass-time line has the same negative slope, -P/l_v, for the same heater power. If the graph is continued until dry, the larger quantity takes longer to boil away and reaches the same empty-apparatus reading.




30. (a)(i) The fan replaces humid air at the wick with drier air, increasing evaporation and water-vapour delivery. (ii) Yes, qualitatively: at greater relative humidity evaporation slows, and at lower humidity it speeds up, so output changes without active electronic control. (b) The evaporative humidifier takes latent heat from water/room air and initially cools it; one may feel cooler. It also increases humidity, which can reduce skin evaporation and later offset this sensation. Fan motor heat and room conditions affect the net result.

31. (a) Stirring makes the tea temperature uniform so the sensor reads a representative value. (b)(i) Q: the sudden cooling begins. (ii) R: the temperature stops falling and starts recovering after the ice has melted. (c) The cooled tea is below room temperature and absorbs energy from the surroundings. (d) Approximately 20 °C, from the final plateau S.

32. (a) T2 is the freezing point of water, 0 °C. (b) Latent heat = 0.12 × 334000 = 40080 J ≈ 40.1 kJ. (c) Starting at freezer temperature T3 < 0, draw a rising section to 0 °C, a horizontal melting plateau at 0 °C, then a rise that gradually levels off at room temperature T1.




33. (a) R. (b)(i) On QR, ice and water coexist at 0 °C; heat entering from the room melts ice rather than raising temperature. (ii) On ST, the water has reached thermal equilibrium with the surroundings, so there is no net heat transfer.

34. (a) 1500 × 300 = [C_kettle + 1.3 × 4200](100 - 25). Thus C_kettle = 540 J $°C^{-1}$. (b) Mass boiled away = 1500 × 600/2260000 = 0.398 kg. Remaining mass = 1.3 - 0.398 = 0.902 kg.

35. (a) Q = 0.020 × 2000(110 - 100) + 0.020 × 2260000 = 45600 J. (b) Using the requested simple estimate from (a), 0.200 × 3900(T - 15) = 45600, so T ≈ 73.5 °C. This approximation ignores additional cooling of the condensed water below 100 °C. Including that cooling gives 45600 + 0.020 × 4200(100 - T) = 0.200 × 3900(T - 15), hence T ≈ 76.0 °C for an ideal insulated jug of negligible heat capacity. (c) Expected textbook response: lower because energy heats the metallic jug and escapes to the surroundings or with uncondensed steam. Strictly, the complete ideal benchmark is 76.0 °C, and the size of those losses determines whether the actual value is also below the simplified 73.5 °C estimate.

## Experiment and article questions

36. (a) The control measures ice melted by environmental heat during the same time; subtract its melted mass from the experimental mass. (b) Smaller without control: too much melted mass is attributed to the heater, making l_f = Pt/m too small. (c) The proposed unheated 100 °C water control does not correct the main error in vaporization: the heated water loses energy to cooler surroundings, whereas the unheated control cools below 100 °C and is not in the same thermal condition. It cannot provide an equivalent boil-off correction. Insulate the heated vessel or use a suitable two-power method instead.

37. Put crushed melting ice in the highly insulated cup with the heating element fully surrounded by ice. Use ice already at 0 °C. Tare the balance for the dry cup (and account for the heater if weighed with it). Start heating at known P and time t; stop at the instant the last ice just melts, so the final water is at about 0 °C. Measure initial ice mass m (or resulting meltwater mass with the same accounting). Estimate l_f = Pt/m. Alternatively, collect/weigh only the water melted during a known timed heating interval if an appropriate draining arrangement is available. Possible error: environmental melting, initially retained meltwater, or energy retained by the heater/cup; these require correction or minimization.

38. (a) Low outside relative humidity: dry air can accept more vapour and allows faster evaporation and stronger cooling. (b) The cooler increases room humidity and works poorly in humid weather; it cannot cool below the incoming air's wet-bulb limit. (c) A fan alone does not lower a closed room's mean air temperature; its motor adds some heat. It can make a person feel cooler by increasing convection and sweat evaporation, or cool a room by bringing in cooler outside air.

# Chapter 4 - Transfer Processes

## 4.1 Conduction

### Checkpoint 1 (p.106)

1. C: from a region at higher temperature to one at lower temperature.

2. B: the copper rod conducts energy fastest.

3. Copper: good conductor. Plastic, water and air: good insulators (poor conductors).

### Checkpoint 2 (p.108)

1. C: free electrons carry energy through metals efficiently.

2. A: only (2), interpreted as more free electrons per unit volume under comparable conditions. Lattice vibrations also transfer energy; metal atoms do not move freely through the solid.

### Practice 4.1 (p.109)

1. C: aluminium removes energy from your hand faster, so the can feels colder.

2. C: fur slows X's cooling; it does not generate heat.

3. C: (1) and (2). Atoms in a solid vibrate around fixed positions rather than travelling from the hot end to the cold end.

4. (a) The insulating handle reduces conduction from the hot metal to the hand and prevents burns. (b) Wood or heat-resistant plastic.

5. Goose-down traps air. Air conducts heat poorly, and the small trapped pockets suppress convection, reducing energy loss from the body.

6. No: a vacuum has no particles to transfer energy by conduction.

7. Fat conducts heat poorly and slows energy transfer from the warm body to the cold surroundings.

8. Leave all three at the same room temperature, then touch them briefly under comparable conditions. The iron nail feels coldest and conducts heat fastest; paper feels warmest and conducts heat slowest; glass is intermediate. Touch is only a qualitative comparison because geometry and contact also affect the sensation.

9. (a) From your warmer hand to either railing. (b) Metal conducts energy away faster than wood, so your hand cools faster on metal.

## 4.2 Convection

### Checkpoint 3 (p.117)

1. Draw arrows upward above the heated base, outward at the surface, downward at the cooler sides, then inward along the bottom. This gives two circulation loops if heating is central.

2. (a) Cold, denser air sinks; warmer air rises to replace it. (b) Shorter for occupants to feel cool, because the cooled air reaches their level sooner; cooling the entire room uniformly is a separate issue.

### Practice 4.2 (p.118)

1. A: ordinary convection requires a fluid, not a solid.

2. (a) Water rises above the central burner, moves outward at the surface, sinks down both sides and returns along the base. (b) Air rises above the heater, spreads along the ceiling, descends at cooler walls and returns toward the heater at lower levels.

3. A vacuum contains no fluid to move and carry energy.

4. In microgravity there is negligible buoyancy-driven convection to pull hot gas upward. With oxygen supplied, fuel and oxygen diffuse in approximately all directions and the flame is approximately spherical.

5. Heat can accumulate because hot air cannot escape freely. The shade may overheat, become damaged or catch fire.

6. Hot air and vapour above tea tend to rise and escape, so a cover reduces convection and evaporation. In an open-top chest freezer, cold dense air remains low inside and warm air remains above it, limiting natural convection exchange.

7. (a) Intended immediate effect: he feels hotter without the jacket. (b) The initially cool jacket traps cool air and briefly slows heat transfer from the hot surroundings. Over longer periods it can trap metabolic heat and hinder cooling; a jacket does not keep him cool indefinitely.

8. (a) Air heated by the candle rises in its chimney, drawing replacement air and smoke downward through the other chimney. The smoke travels beneath the divider and rises with the warmed air above the candle. (b) Solid particles cannot undergo bulk circulation; they remain near fixed positions.

## 4.3 Radiation

### Checkpoint 4 (p.124)

1. Good; warmer.

2. D: all three increase the cooling rate under comparable conditions - stronger emission, greater exposed area per amount of soup, and a colder environment.

### Checkpoint 5 (p.130)

1. A: the shiny stainless-steel wall reduces radiation transfer. A vacuum prevents conduction and convection, but not radiation.

2. (a) Metal. (b) Black. (c) Conduction, for transfer directly to the adjacent air; convection then carries the warmed air away. Increased surface area also increases radiative loss.

### Practice 4.3 (p.132)

1. D: all objects above absolute zero emit thermal radiation.

2. D: all three use light surfaces to reduce absorption of sunlight in the textbook explanation.

3. (a) Net energy flows from the warmer surroundings to the ice. (b) The black-cloth-covered block: black absorbs more solar radiation and transfers more energy to the ice under comparable conditions.

4. A light, low-emissivity surface reduces radiation loss from the warm balloon, so less fuel is needed to maintain temperature. This is the textbook approximation; actual thermal-infrared emissivity depends on the coating as well as its visible colour.

5. (a) The black flask, because its surface emits thermal radiation more effectively. (b) Net energy flows from the hot water/flasks to the cooler surroundings in both cases.

6. Transparent plastic outside, black coat inside. Sunlight passes through the plastic and is absorbed by the black coat; the outer plastic reduces airflow and convective heat loss.

7. Light summer uniforms absorb less sunlight and help keep the wearer cooler. Dark winter uniforms absorb more sunlight and help keep the wearer warmer.

8. The white surface absorbs less incoming radiation and paper is a poor conductor. Cold dense air also tends to remain in the open-top box, limiting convection exchange.

9. (a) The shiny inner surfaces are poor emitters/absorbers of thermal radiation and reflect radiation, reducing radiative energy transfer to the cold drinks. (b) Yes: the insulation slows conduction/convection and the shiny lining reduces radiative loss from hot drinks. Use Kelvin temperatures in all gas-law ratios: T(K) = temperature(°C) + 273. Use absolute pressures; R = 8.31 J $mol^{-1}$ $K^{-1}$ and $N_A = 6.02 \times 10^{23}$ $mol^{-1}$.

# Revision exercise 4

Printed textbook pages 135-140. All 30 numbered questions.

## Concept traps and multiple choice

1. False. The vacuum prevents conduction and convection across the gap; shiny surfaces reduce radiation.

2. False as worded. A heated portion of fluid expands and becomes less dense because its molecules become farther apart; the individual molecules do not expand. The less-dense fluid rises under buoyancy.

3. C: water above the heater rises and cooler water returns through a loop above it. Heating midway does not produce strong circulation through the cold water below the heater.

4. B: radiation from the sun is the main relevant transfer process.

5. A: only (2). The jacket slows loss of body energy and does not generate heat.

6. D: all three. Radiation and rising hot gases heat the meat, while conduction carries heat through the meat and from any contacting hot grill surface.

7. B: (1) and (3). Insulation slows both cooling of hot contents and warming of cold contents.

8. B: (1) and (2) in the textbook's ordinary material comparisons. Solid metal does not undergo bulk convection merely because electrons are mobile.

9. B: convection carries the hot gas and ash upward.

10. A: the two containers present the smallest projected area perpendicular to the incoming sunlight in this arrangement, minimizing total solar energy intercepted.

11. A: radiation travels downward from the filament; natural hot-air convection is upward.

12. B: shiny aluminium foil mainly reduces radiative loss in this comparison. Aluminium itself is a good conductor.

13. D: energy leaves the foot faster into tile than carpet.

14. A: (1) and (2). A vacuum does not suppress thermal radiation.

15. C is incorrect. The outer case should insulate the cooker rather than conduct heat away readily.

16. A: the shallower pool has less water mass per unit sunlit surface area, so its temperature rises faster under equal sunlight intensity.

17. D: $t_Y > t_X$ because the vacuum flask reduces the rate of heat gain from the surroundings.

## Conventional questions

18. (a) The double walls enclose insulating material/trapped air, reducing conduction and convection into the compartment. (b) The seal stops warm room air entering and cold air escaping, reducing convective exchange.

19. Sunlight passes through the glass and is absorbed by internal surfaces, heating the building. Glass limits free air exchange and is relatively opaque to much outgoing thermal infrared radiation, so more cooling power may be needed.

20. (a) Aluminium spreads energy laterally from hotter regions to cooler regions efficiently, reducing hot spots; stainless steel provides the cooking/protective surfaces. (b) The shiny stainless-steel exterior has low emissivity and reduces radiative loss. A fitted lid, if present, additionally reduces convection and evaporation.

21. (a) Silvery-white tanks reflect much incoming solar radiation, reducing fuel heating and excessive evaporation/pressure. (b) The shiny blanket has low emissivity and reduces radiative loss; it also blocks wind and reduces evaporation, keeping the runner warm. (c) Place the shield in the incoming sunlight at the window, preferably outside, with its reflective face directed toward the sun so it reflects radiation before it heats the room.

22. Light-coloured paint reflects more sunlight and absorbs less solar radiation, reducing heating of the aircraft and the demand for cabin cooling, under otherwise comparable conditions.

23. (a) Trapped air conducts heat much less readily than glass; a narrow sealed gap also suppresses air circulation. Thus the gap gives greater thermal resistance than the same thickness of solid glass. (b) A vacuum further improves insulation because there are no gas particles for conduction or convection across it. Radiation and conduction through edge seals/supports remain, so it does not stop all heat transfer.

24. (a) The fan produces forced convection, bringing hot air to the food and carrying cooler air back to the heater. This makes heating faster and more uniform. (b) The poorly conducting lining reduces heat transfer into the oven structure and outward loss. (c) Shiny walls reflect thermal radiation back toward the food and are poor emitters/absorbers, reducing energy lost into the walls.

25. (a) The vacuum gap reduces conduction and convection from the warm surroundings into the ice cream. (b) Clear glass still allows solar radiation through; a vacuum does not stop radiation. An unsealed opening can also admit warm air. (c) Add reflective/silvered surfaces or an opaque shiny outer cover to reflect sunlight; add a well-insulated fitted lid if open.

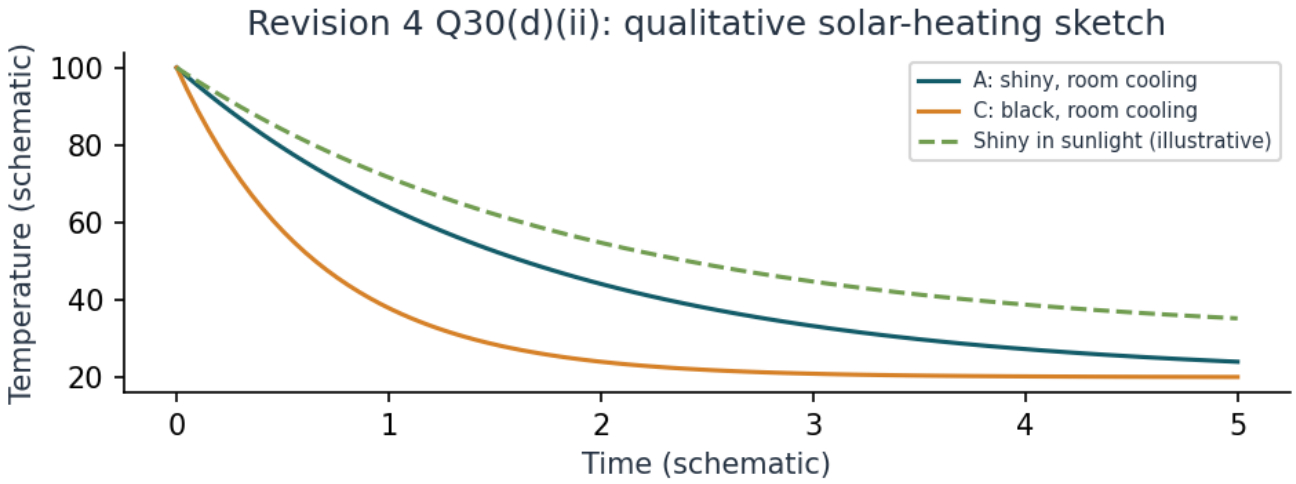
26. (a) Glass admits sunlight while reducing hot-air escape and evaporation from the water; it also reduces some outgoing thermal-infrared transfer. (b) $Q = 0.5 \times 4200 \times (60 - 20) = 84000$ J = 84 kJ. (c) The shiny board reflects additional sunlight into the cooker, increasing collected solar power.

27. (a) Water and glass conduct heat poorly. Heating the top leaves the hot, less-dense water above the colder water, so little convection carries heat downward to the ice. (b) A metal tube conducts heat down its wall much faster, so the bottom ice melts more rapidly. (c) Bottom heating creates a convection current: warmed water rises and colder water descends to replace it.

28. (a) Radiation. (b) Land has a smaller effective specific heat/heat capacity than the sea and cools more for a comparable energy loss; sea mixing also moderates its surface cooling. (c) Label land/cold air as cooler and sea/air above it as warmer. Draw near-surface arrows from land to sea, rising arrows above the warmer sea, upper-level return arrows toward land, and descending arrows over land.

29. (a) Net heat flows from the hot food to the cooler surroundings. (b)(i) Polyfoam traps air and is a poor conductor. (ii) The lid prevents bulk air exchange and the small trapped air cells suppress convection. (iii) In the textbook model the white surface is a poorer radiator than a dull black surface. Actual infrared emissivity depends on the material as well as visible colour. (c) The container slows energy gain by cold food, so its temperature increases more slowly; it does not actively refrigerate it.

30. (a)(i) C is dull black. (ii) A is shiny. (b) Dull black is the best emitter, so it initially cools fastest; shiny paper is a poor emitter and cools slowest. All approach room temperature. (c) Later, C is much closer to room temperature and has a smaller temperature difference, so its instantaneous cooling rate can be less than A's. (d)(i) Sunlight supplies additional energy to the unwrapped beaker, reducing its net cooling rate; it may eventually level off above the previous room-temperature plateau. (ii) For the shiny beaker draw a curve starting at the same initial temperature and lying above its previous cooling curve A, falling more slowly and approaching a solar-heated equilibrium. The precise slope and endpoint require the radiation intensity; do not assume a specified final temperature from the information given.



# Chapter 5 - Gases

## 5.1 The gas laws

### Checkpoint 1 (p.151)

1. $F = pA = 110000 \times 0.25^2 = 6875$ N $\approx 6.88 \times 10^3$ N on each wall.

2. (a) Bourdon gauge / pressure gauge. (b) Approximately $1.0 \times 10^5$ N $m^{-2}$, using the indicated inner scale.

### Checkpoint 2 (p.154)

1. (a) Yes. (b) Yes. (c) No: N $m^2$ is force multiplied by area, not force per area.

2. The remaining volume is 55% of its original value: $p_2 = 100/0.55 = 182$ kPa, assuming constant temperature.

3. (a) Fixed amount/mass of gas at constant temperature, with ideal-gas behaviour. (b) $p_2 = 100 \times 50/45 = 111$ kPa.

### Checkpoint 3 (p.157)

1. A: only (3). The unit symbol is capital K, and $T_K = T_C + 273$.

2. Body temperature: 310 K. Mercury melting point: -39 °C.

3. $T_2 = 3 \times 300 = 900$ K = 627 °C.

### Checkpoint 4 (p.160)

1. (a) Volume increases linearly with Celsius temperature, but is not directly proportional to it. Volume is directly proportional to Kelvin temperature at fixed pressure and gas amount. (b) Extend the line backward to V = 0 and mark the intercept -273 °C.

2. $V_2 = 1 \times (117 + 273)/(27 + 273) = 1.30$ $m^3$.

### Checkpoint 5 (p.164)

1. $p_2 = 100 \times (80/70) \times (306/300) = 116.6$ kPa $\approx 117$ kPa.

2. $V = 5 \times 7 \times 2.2 = 77$ $m^3$. Taking atmospheric pressure as $1.0 \times 10^5$ Pa, $n = pV/(RT) = 3109$ mol $\approx 3.11 \times 10^3$ mol. Using $1.013 \times 10^5$ Pa gives about $3.15 \times 10^3$ mol.

### Checkpoint 6 (p.166)

1. (a) -273 °C: the nonzero intercept at 0 indicates a Celsius-temperature axis. (b) Slope = nR/V, for a fixed container volume. (c) A steeper straight line with the same temperature-axis intercept at -273 °C; its pressure at 0 °C is higher.

### Practice 5.1 (pp.167-168)

1. B: only (2), because a change of 100 °C equals a change of 100 K.

2. A: approximately 290 K = 17 °C.

3. C: the graph gives $p/T \approx 0.25$ kPa $K^{-1}$, so $p \approx 150$ kPa at 600 K.

4. B: mol.

5. B: high temperature and low pressure.

6. B: $pV = 105000/0.70 = 150000$ Pa $m^3$; $n = 150000/(8.31 \times 293) = 61.6$ mol $\approx 62$ mol.

7. $T_2 = 293 \times 100/90 = 325.6$ K = 52.6 °C.

8. Atmospheric pressure on the underside provides an upward force that supports the plate and water. The sealed arrangement prevents free entry of air; the pressure just inside the plate is sufficiently lower for the upward pressure difference to support the load.

9. (a) Pressure increases as temperature rises in the closed cooker; steam production also contributes. (b) Excess pressure can exceed the cooker's strength, causing rupture and release of hot steam/water.

10. $p_2 = 50 \times (473/173)/1.02 = 134$ kPa.

11. (a) It expands. (b) Pumping lowers the surrounding pressure, so the trapped gas expands; at approximately constant temperature, pV is constant for the trapped gas.

12. (a) At 120 kPa, $1/V \approx 100$ $m^{-3}$; $V \approx 0.010$ $m^3$. (b) p is proportional to 1/V: the best-fit straight line extrapolates approximately through the origin, so pV is constant at the fixed temperature. For example, approximately (1/V,p) = (100,120) and (125,150) give $pV \approx 1200$ Pa $m^3$ in each case.

13. (a) $p_2 = p_1V_1/V_2$. (b) $p_3 = p_2T_2/T_1 = p_1V_1T_2/(V_2T_1)$. (c) The same $p_3 = p_1V_1T_2/(V_2T_1)$; final pressure depends on the final state, not the route.

14. $N_X/N_Y = (V_X/T_X)/(V_Y/T_Y) = (1.2/293)/(0.9/298) = 1.36$. Thus $N_X:N_Y \approx 1.36:1$.

15. Draw a straight line through the origin with one-quarter the original slope. Since $V = (nR/p)T$, replacing n by n/2 and p by 2p makes the slope $nR/(4p)$.

16. Assume the temperature is maintained at its original value. (a) $p_X = (1.5/2.4)p_Y = 0.625p_Y$. (b) Each container finally has 1.95 mol, so $p_{final} = (1.95/2.4)p_Y = 0.8125p_Y$. (c) Increase in X = (1.95 - 1.5)/1.5 × 100% = 30%.

## 5.2 The kinetic theory of gases

### Checkpoint 7 (p.175)

1. Mean square speed = $3pV/M = 3 \times 120000 \times (40 \times 10^{-6})/(6.5 \times 10^{-5}) = 2.22 \times 10^5$ $m^2$ $s^{-2}$. This is mean square speed, not root-mean-square speed.

2. At T = 298 K: (a) Total KE = $(3/2)nRT = 1.86 \times 10^3$ J. (b) KE of one mole = $(3/2)RT = 3.71 \times 10^3$ J. (c) Mean KE per molecule = $(3/2)RT/N_A = 6.17 \times 10^{-21}$ J.

### Checkpoint 8 (p.179)

1. A: trapped air molecules bombard the water surface and exert pressure, preventing the glass from filling completely. Some water can enter as the trapped air compresses.

2. (a) Gas molecules. (b) Gas pressure / external load determining equilibrium gas pressure. (c) Gas temperature. (d) Gas volume.

### Practice 5.2 (p.182)

1. C: increased temperature.

2. C: molecules have a distribution of speeds, not one common speed.

3. D under the usual interpretation: increase gas amount at fixed volume; increase density; or decrease volume at fixed gas amount. At fixed temperature, $p = (N/V)kT$, so each specified change increases number density under these conditions.

4. B: total translational KE = $(3/2)NkT$; more molecules give a larger slope.

5. $c_{rms} = \sqrt{[3RT/(N_A m)]} = \sqrt{[3 \times 8.31 \times 373/(6.02 \times 10^{23} \times 3.34 \times 10^{-27})]} = 2.15 \times 10^3$ m $s^{-1}$.

6. (a) Continuous irregular, random zigzag motion (Brownian motion). (b) Gas molecules strike it unevenly from different directions; the resulting fluctuating force changes its motion. (c) Motion becomes less vigorous as the gas molecules have lower average kinetic energy.

7. (a) The average speed increases. (b) Faster molecules strike the walls more frequently and transfer more momentum per collision. The rate of momentum transfer per unit area increases, so pressure increases at fixed volume.

8. Pumping adds molecules into the same volume, increasing their collision rate with the tyre walls and therefore the force per unit area. Compression heating may increase pressure further temporarily.

9. $c_{rms} = \sqrt{3RT/M_{molar}} = \sqrt{3 \times 8.31 \times 298/0.0337} = 470\ m\ s^{-1}$.

10. $\Delta E = (3/2)(N/N_A)R\Delta T = (3/2)[7.28 \times 10^{24}/(6.02 \times 10^{23})] \times 8.31 \times (80 - 25) = 8.29 \times 10^3\ J$.

11. Since average molecular KE is proportional to Kelvin temperature, and T is proportional to pV for a fixed gas amount: (a) Triples. (b) Becomes nine times the initial value. (c) Unchanged.

12. (a) m = mass of one molecule; Nm = total mass of the gas. (b) Total translational KE $E = (1/2)Nm\ mean(c^2) = (3/2)pV$. For one mole $pV = RT$, so $E = (3/2)RT$.

# Revision exercise 5

Printed textbook pages 185-192. All 32 numbered questions. Use absolute pressure, Kelvin temperature $T = \theta + 273$, $R = 8.31\ J\ mol^{-1}\ K^{-1}$ and $N_A = 6.02 \times 10^{23}\ mol^{-1}$. Molecular KE refers to the translational KE in this textbook's ideal-gas model.

## Concept traps and multiple choice

1. False. $3RT/(2N_A)$ is the average KE of one molecule. Total ideal-gas internal energy in the stated model is $(3/2)nRT = N \times 3RT/(2N_A)$.

2. False. Ideal-gas molecules collide with one another as well as the walls; collisions are elastic.

3. A: only (3). N is the number of molecules, $n = N/N_A$ is the number of moles, and Nm is total gas mass.

4. C: equal temperature guarantees equal average molecular KE. Molecular speed also depends on molecular mass, and total KE depends on molecule number.

5. D: $c_{rms,new}/u = \sqrt{(80 + 273)/(20 + 273)} = 1.098 \approx 1.10$.

6. A: p is proportional to $\theta + 273$, so the Celsius p-θ graph is straight with positive pressure at 0 °C.

7. B: during landing, outside pressure exceeds the pressure of the trapped air and compresses the bottle.

8. B: $T_Y > T_Z = T_X$. Along the straight segment joining two equal-pV endpoints, the intermediate pV is greater than the endpoint value; T is proportional to pV.

9. B: only (3). Gas fills its available volume, and the flexible balloon normally comes to approximate mechanical equilibrium rather than maintaining a lower internal pressure indefinitely.

10. A: volume increases. The ratio p/T (the slope of a line from the origin to a point on the graph) decreases from X to Y; $V = nR/(p/T)$ therefore increases.

11. D: (2) and (3). Conducting walls allow equal temperatures. Equal molar masses then give equal r.m.s. speeds; equal total masses alone do not.

12. A: (1) and (2). Cooling at fixed pressure reduces volume and average molecular separation; r.m.s. speed falls. Collision rate on a fixed-area piston actually increases as density rises: rate $\propto (N/V)\sqrt{T} \propto 1/\sqrt{T}$.

13. A: only (1). At equal pressure, a hotter gas has lower number density and greater average spacing. Molecular speeds are distributed; not every molecule is faster. Wall-collision frequency per unit area is not equal.

14. A: halving molecule number halves both the slope and the vertical intercept of the Celsius p-θ graph, while retaining the same θ-axis intercept at -273 °C.

15. D is incorrect. The final pressure is [2pV + p(2V)]/(V + 2V) = 4p/3, not 3p/2. Initially each vessel contains the same molecule number.

## Conventional questions

16. (a) When the ruler is struck rapidly, it tries to lift the wide newspaper before air can flow beneath it. Pressure below the paper drops, while atmospheric pressure above acts over its large area, producing a large downward resultant force that resists lifting. (b) Spread a large newspaper flat and smooth on the table with little trapped air; strike the projecting ruler sharply so air has little time to enter underneath. Both are needed for a strong effect.

17. (a) V = 100 $cm^3$ = 1.00 × $10^{-4}$ $m^3$, T = 298 K. n = pV/(RT) = 100000 × $10^{-4}$/(8.31 × 298) = 4.04 × $10^{-3}$ mol. N = nN_A = 2.43 × $10^{21}$ molecules. (b) Molecules ejected per second = [p/(RT)] × |dV/dt| × N_A = [100000/(8.31 × 298)] × $10^{-6}$ × 6.02 × $10^{23}$ = 2.43 × $10^{19}$ $s^{-1}$.

18. (a) Not justified. v is one molecule's instantaneous speed; r.m.s. speed is sqrt[average($c^2$)] over all molecules. (b) Not necessarily at a particular instant. Raising temperature raises the ensemble's mean KE and r.m.s. speed, but collisions continually change an individual molecule's speed, which may be below its earlier value.

19. (a) Approximately atmospheric pressure while connected to outside air (apart from small pressure differences needed for flow and balloon tension). (b) The balloons inflate. Pulling the diaphragm down increases the bell jar's gas volume and lowers pressure outside the balloons; atmospheric air enters through the tube and expands them. (c) The balloons tend to shrink: warming the trapped bell-jar gas raises its pressure, squeezing the balloons and expelling some of their air through the open tube.

20. (a) At fixed T and V, n is proportional to p. Escaped fraction = (220 - 100)/220 = 54.5%. These are treated as absolute pressures as stated. (b)(i) r.m.s. speed unchanged because temperature and molecular mass are unchanged. (ii) Total internal energy decreases to 100/220 = 45.5% of its initial value because fewer molecules remain with the same mean KE. In this model U_i = (3/2)p_iV = 6600 J and U_f = 3000 J.

21. (a) Equate pV = (1/3)Nm mean($c^2$) to pV = (N/N_A)RT: c_rms = sqrt[3RT/(N_A m)] = sqrt(3kT/m). (b) E_total = (1/2)Nm mean($c^2$) = (3/2)pV = (3/2)nRT. (c) E = 1.5 × 3.5 × 8.31 × 343 = 1.50 × $10^4$ J. (d) High temperature and low pressure.

22. (a)(i) Sunlight is absorbed most strongly near the water surface. Water conducts heat poorly, and warm less-dense surface water remains above cooler denser water, so natural convection does not readily carry the solar heat downward (for ordinary water temperatures above about 4 °C). (ii) Interpreting the stated 10% temperature reduction on the Kelvin scale, T_depth = 0.90T_surface. V_surface/V_depth = (p_depth/p_surface)(T_surface/T_depth) = 2/0.90 = 2.22. Thus volume increases by 122%, or by 1.22 times the original volume. A percentage specified only on a Celsius scale would not be enough for this numerical gas-law calculation. (b) Trapped lung gas expands during ascent; holding the breath or failing to vent/equalize appropriately can overexpand and injure the lungs.

23. (a) n = 100000 × 5/(8.31 × 300) = 201 mol. (b)(i) V2 = 5 × (100/80) × (280/300) = 5.83 $m^3$. (ii) ΔU = (3/2)nR(280 - 300) = -5.00 × $10^4$ J; internal energy decreases by 50.0 kJ. (iii) c_rms = sqrt[3 × 8.31 × 280/(6.02 × $10^{23}$ × 6.64 × $10^{-27}$)] = 1.32 × $10^3$ m $s^{-1}$.

24. (a)(i) The total air molecule number decreases as air is sucked out through the straw. (ii) Average molecular speed is approximately unchanged if temperature is unchanged. (b) Removing molecules reduces the rate of molecular momentum transfer to the carton walls, so inside pressure falls below atmospheric pressure. The resulting inward force collapses the carton. (c) Open the seal to admit air, and gently reshape it if necessary. Equalizing inside and outside pressure removes the inward pressure difference. Alternatively, gently warm the sealed trapped gas to raise pressure, but opening it is the simple method.

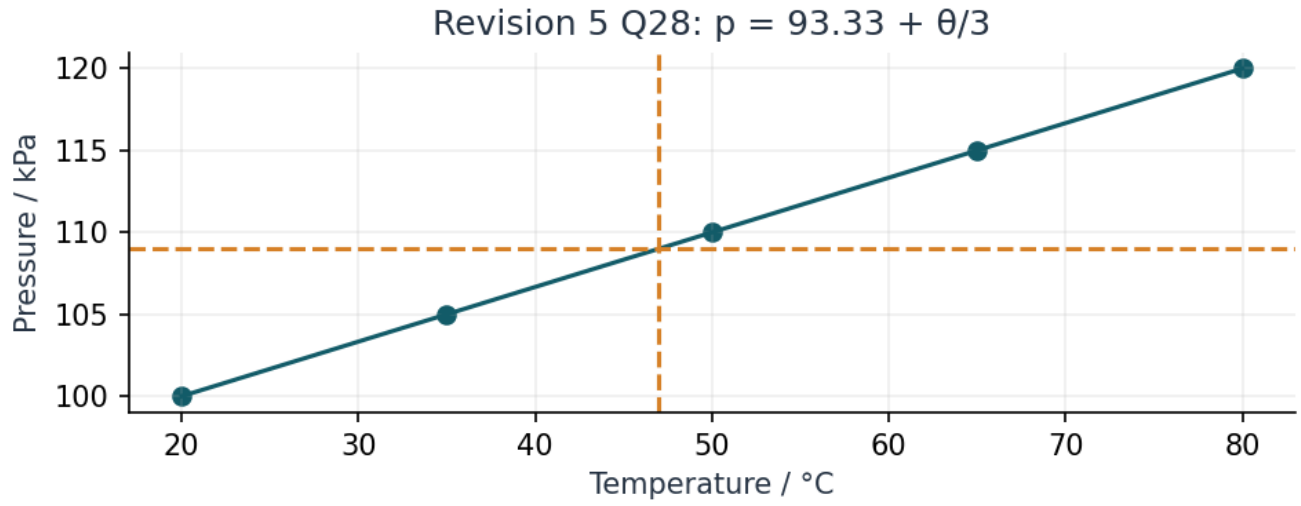
25. (a)(i) Approximately atmospheric pressure, since the piston is essentially weightless and free to move. (ii) The piston rises. Heating increases molecular speeds; the resulting extra momentum transfer initially tends to raise pressure, pushing the piston up until the gas expands enough for its pressure to match the outside pressure again. (b) At fixed 80 °C, mean KE/speed and total internal energy remain unchanged for the sealed fixed gas amount. Expansion lowers number density and wall-collision rate per unit area, so pressure decreases. (c) At fixed volume the gas cools: molecules move more slowly and collide less frequently and less forcefully with the walls, so pressure decreases.

26. (a)(i) Randomly moving molecules collide with the walls and change momentum. The reaction force on the wall per unit area is gas pressure. (ii) Internal energy is the total microscopic molecular kinetic and potential energy; for the model ideal gas, intermolecular PE is taken as zero, leaving molecular KE. (b)(i) Ideal molecules have negligible volume and no intermolecular forces except during elastic collisions; real molecules have finite volume and intermolecular attractions/repulsions. (ii) c_rms ∝ 1/sqrt(m) at fixed T. Molecular masses H2:O2 = 2:32, so c_H2/c_O2 = sqrt(32/2) = 4; ratio 4:1.

27. (a)(i) Initial equivalent atmospheric-volume content = 6000 $cm^3$. Final equivalent atmospheric-volume content = (156/100) × 6000 = 9360 $cm^3$. Additional atmospheric air = 9360 - 6000 = 3360 $cm^3$. (ii) Minimum strokes = 3360/120 = 28. (b) Added molecules increase number density and collision rate with the ball walls at the same temperature; momentum transfer per second and therefore pressure increase.

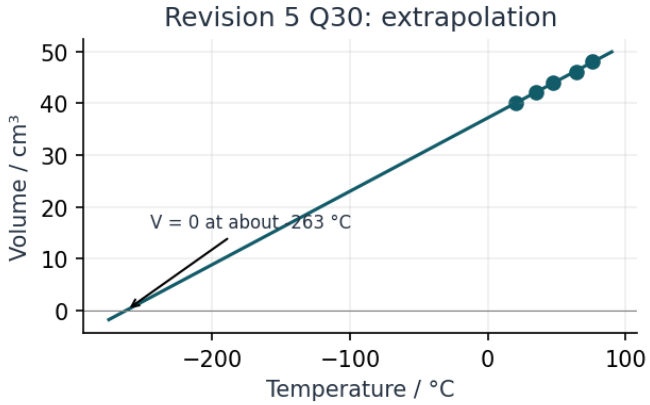
## Experiment and article questions

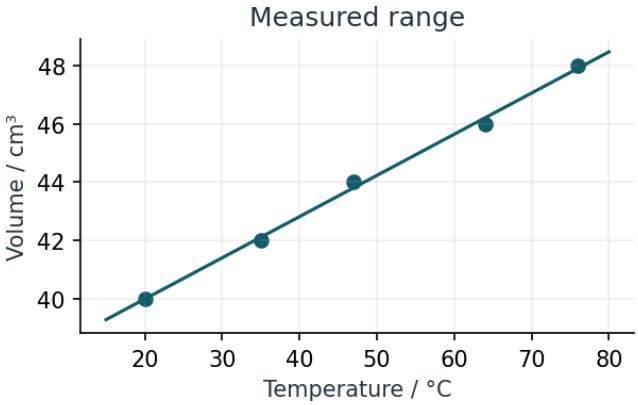
28. (a) The flask is not fully immersed, so all the trapped gas may not share the measured water temperature; immerse it adequately. The thermometer bulb touches/is at the heated beaker base, so it can read the base rather than representative water temperature; suspend it clear of the bottom near the flask. The long connecting tube contains appreciable gas outside the bath at a different temperature; use the shortest practical narrow connector and minimize unheated dead volume. (b) Plot (θ/°C,p/kPa) = (20,100), (35,105), (50,110), (65,115), (80,120). Straight line: p = 93.33 + θ/3. The supplied experimental line extrapolates to about -280 °C, a measurement estimate rather than the exact absolute-zero value. (c) 320 K = 47 °C; p = 93.33 + 47/3 = 109 kPa.



29. (a) Constant gas pressure (and fixed gas amount). (b) Approximately atmospheric pressure when the oil's weight is negligible. (c) Keep the capillary's open end unobstructed and let the oil thread move freely so pressure stays equal to atmospheric pressure. (d) Stirring makes the bath temperature uniform and helps the gas reach the indicated temperature. (e) The glass thermometer can break, causing cuts and mercury contamination. (f) A second unheated apparatus does not correct the gas's measured equilibrium V-T relation; energy supplied is not being calculated. More useful improvements are ensuring equilibrium, constant pressure, no leaks and accurate volume/temperature readings.

30. (a) Stir the water and allow thermal equilibrium before each reading; read the scale at eye level and ensure the piston moves freely. (b) Direct flame heating can damage/melt the syringe and gives highly nonuniform, uncontrolled gas temperature. A water bath provides gentle, more uniform heating. (c)(i) Plot ($\theta$/°C,V/cm$^3$) = (20,40), (35,42), (47,44), (64,46), (76,48) and draw a best-fit straight line. A least-squares line is $V \approx 37.15 + 0.1415\theta$. (ii) Extrapolate to V = 0: $\theta \approx -263$ °C. A sensible graph fit may give about -260 to -270 °C; this is the estimate from the supplied data, not an instruction to force the line through -273 °C. (iii) From the 20 °C point, $n = 100000 \times 40 \times 10^{-6}/(8.31 \times 293) = 1.64 \times 10^{-3}$ mol; other points give approximately $1.65 \times 10^{-3}$ mol within experimental scatter.




31. (a) Stir the bath thoroughly and wait after each heating adjustment until the thermometer reading and air-column length are steady. (b)(i) L = 64 + (80 - 64)(65 - 20)/(92 - 20) = 74 mm. (ii) Slope = 16/72 mm °C$^{-1}$; setting L = 0 gives $\theta$ = 20 - 64/(16/72) = -268 °C.

32. (a) With most air removed, inside pressure is very low. Atmospheric pressure outside produces a large inward resultant force holding the shells together. Opening the valve admits air and equalizes the pressure. (b) With diameter 0.50 m and negligible internal pressure, $F = p_{atm} A = 100000 \times \pi \times (0.25)^2 = 1.96 \times 10^4$ N on each cup (about 19.6 kN). Use the circular projected area, not the hemispherical curved surface area; using $1.013 \times 10^5$ Pa gives about 19.9 kN.