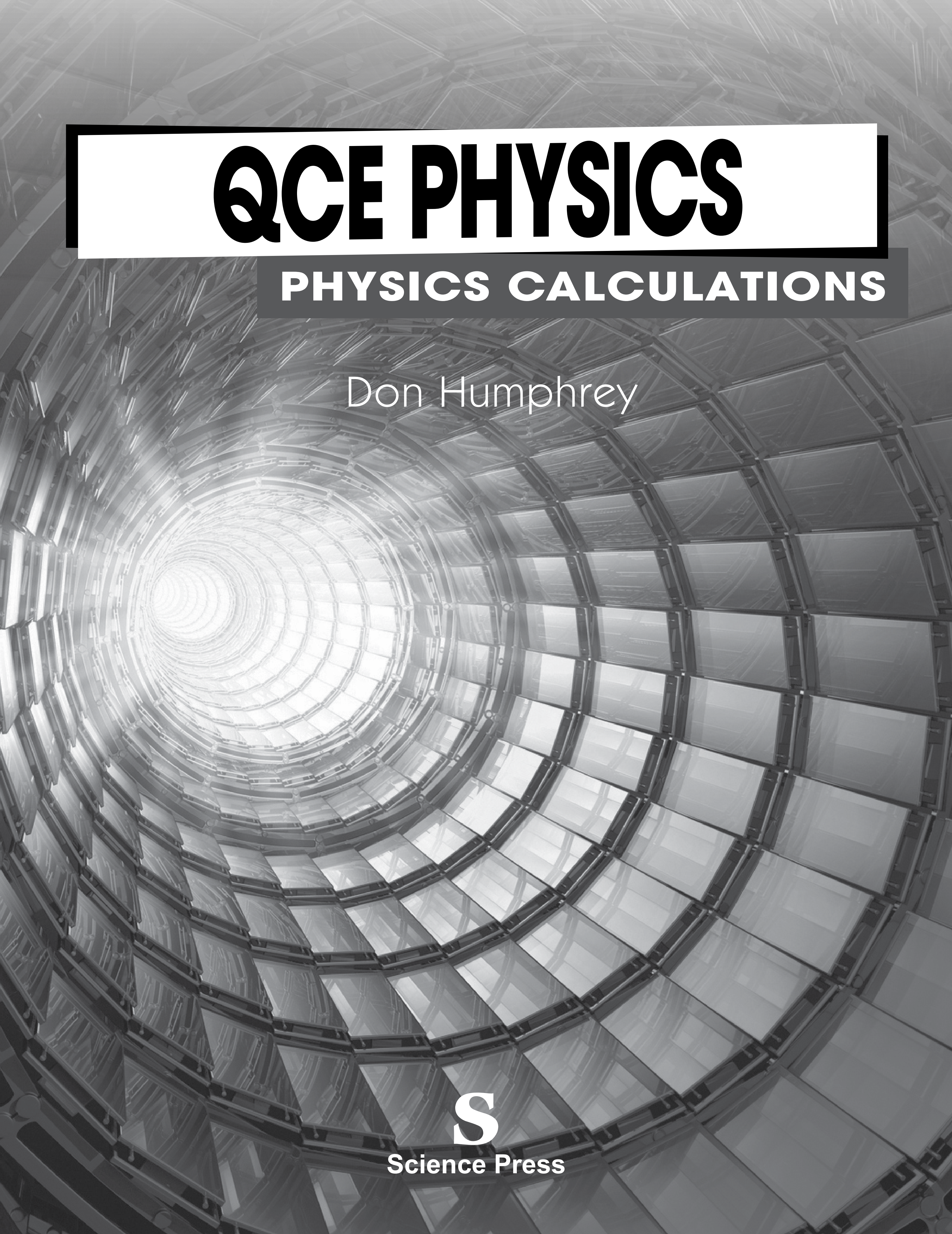

QCE PHYSICS

PHYSICS CALCULATIONS

Don Humphrey

Science Press

This book is dedicated to the memory of my wife.
Without her patience and support I could not have completed the task.

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Contents

Introduction

A significant amount of the Queensland Physics syllabus involves the solving of numerical problems. The object of this book is to provide sets of simple graded exercises which require the use of formulas mentioned in the syllabus. The sets of exercises are designed to be attempted immediately following the introduction of the theory or for homework. Although the formulas are given in the examination papers, only by practice will you develop the facility to recognise a problem and solve it.

Detailed answers are included. In some cases the solutions can be obtained via different pathways but should agree in the end with the answers provided.

Words to Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

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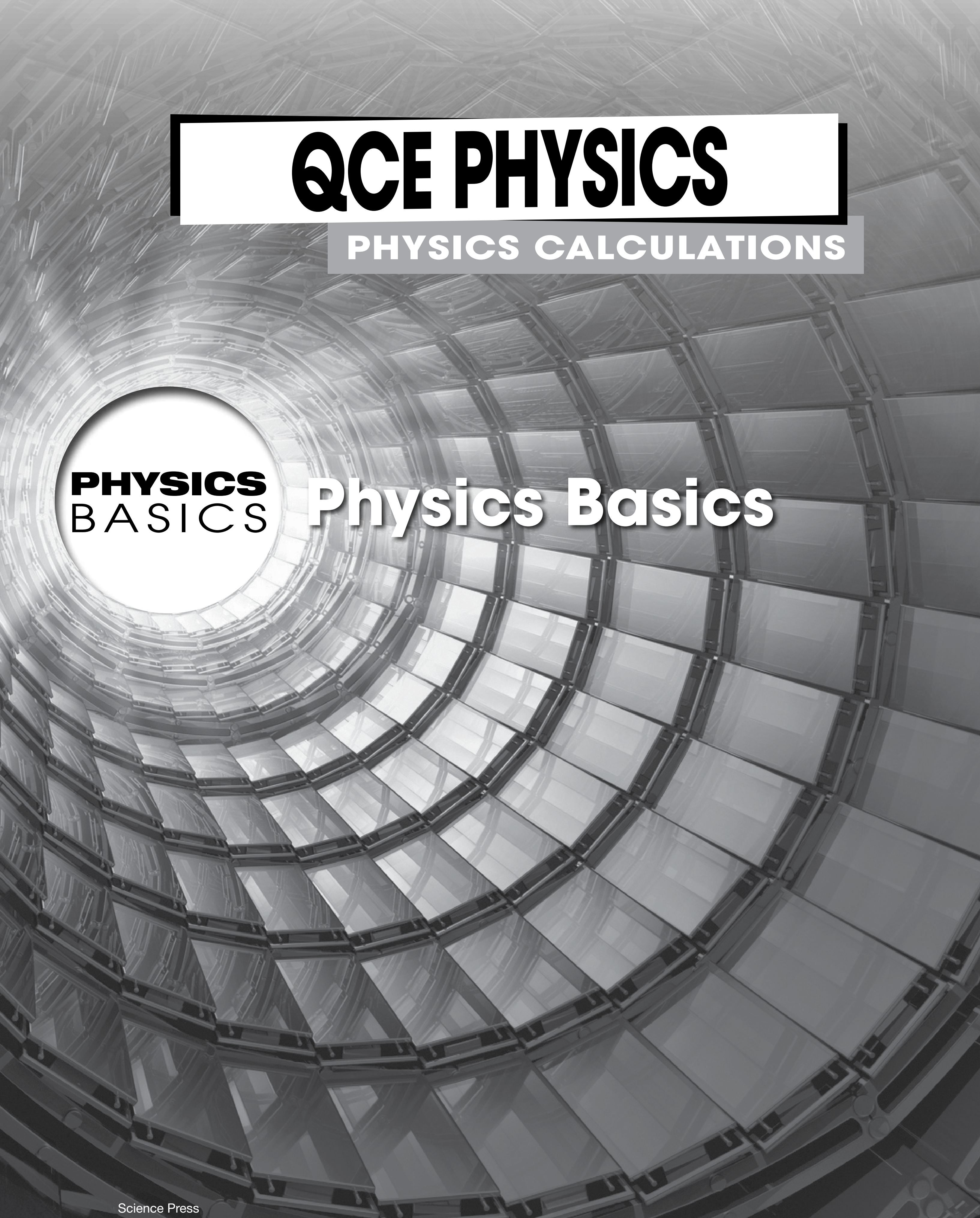

PHYSICS BASICS

Physics Basics

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1. Physics Basics

Units of measurement

In the SI system of units, the fundamental quantities are as follows.

Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Light Intensity	candela	cd
Amount of substance	mole	mol

These are compounded and subdivided as follows.

tera	10^{12}	T
giga	10^{9}	G
mega	10^{6}	M
kilo	10^{3}	k
*hecta	10^{2}	H
*deca	10^{1}	Da
*deci	10^{-1}	d
*centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ
nano	10^{-9}	n
pico	10^{-12}	p
femto	10^{-15}	f
atto	10^{-18}	a

* Commonly used but not part of SI.

Questions

In each of the following, express your answer as a power of 10. How many:

1. Millimetres (mm) in 1 metre (m)?

2. Centigrams (cg) in 1 kilogram (kg)?

3. Microamperes (μA) in 1 milliampere (mA)?

4. Seconds (s) in 1 millisecond (ms)?

5. Megamoles (Mmol) in 1 kilomole (kmol)?

6. Kilocandelas (kcd) in 1 microcandela (μcd)?

7. Nanokelvins (nK) in 1 millikelvin (mK)?

8. Gigametres (Gm) in 1 kilometre (km)?

9. Picograms (pg) in a decigram (dg)?

10. Attoseconds (as) in 1 terasecond (Ts)?

Scientific notation and significant figures

Applying scientific notation to a number means expressing it as a number between 1 and 10 times 10 to the appropriate power, e.g. $40\ 000 = 4 \times 10^4$ and $0.000\ 005 = 5 \times 10^{-6}$.

Significant figures are those which are accurately known. A general rule is that the answer to a problem should not contain more significant figures than any of the data input.

Examples of correcting to two significant figures are $8.493 \times 10^6 \sim 8.5 \times 10^6$ and $7.0048 \times 10^{-2} \sim 7.0 \times 10^{-2}$.

Order of magnitude

The order of magnitude of a number is the power of 10 nearest to the number. It is often convenient to change a number to scientific notation before working out the order of magnitude.

For example:

$7634.25 = 7.63425 \times I0^3$ which is approximately $10 \times I0^3$ or $I0^4$

$0.00236 = 2.36 \times I0^{-3}$ which is approximately $1 \times I0^{-3}$ or $I0^{-3}$

Questions

For Questions 11 to 20, write each (or perform the calculation and write the answer) expressing the answer in scientific notation correct to *two* significant figures.

11. 7505.23

12. 0.003425

13. 70.2×34.2

14. $1578.3 + 0.400$

15. $\dfrac{0.600 \times 7020.0960}{0.0960}$

16. $\dfrac{1.53}{42.89 \times 8.4}$

17. $\dfrac{0.8235 \times 445.7}{76.9 \times 0.00930}$

18. 20.4×10^{-7}

19. 134×10^{8}

20. $\dfrac{(2.4 \times 10^{-3}) \times (5.6 \times 10^{4})}{(3.0 \times 10^{7})^{4}}$

For Questions 21 to 30, identify the order of magnitude.

21. 8.2×10^{-4}

22. 3.5×10^{7}

23. 73.6

24. 0.00901

25. 863.7×10^{-5}

26. 0.01673×10^{6}

27. $3.5 \times 10^{6} \times 9.2 \times 10^{-4}$

28. $\dfrac{7.6 \times 10^{-5}}{1.9 \times 10^{4}}$

29. The number of seconds in a day.

30. The number of hours in a year.

31. How many millimetres (mm) in 4.5 metres (m)?

32. How many nanoseconds (ns) in 276 seconds (s)?

33. How many kilograms (kg) in 0.359 milligrams (mg)?

34. Express the following in scientific notation correct to two significant figures.

(a) 0.003778 (b) 70.2×34.2 (c) $\dfrac{2.64}{5.96 \times 24.2}$

35. Identify the order of magnitude of each of the following.

(a) 7.4×10^{-5} (b) $2.4 \times 10^{3} \times 1.8 \times 10^{-5}$ (c) $\dfrac{8.64 \times 10^{-7}}{2.95 \times 10^{3}}$

2. Errors and Absolute Uncertainty Of the Mean

- Random errors: Add the readings, work out the deviations from the mean, take the greatest deviation.

For example:

	Readings	Deviations
	2.543	+0.002
	2.539	−0.002
	2.540	−0.001
	2.541	0.000
SUM	10.163	
MEAN	2.541	
VALUE	2.541 ± 0.002	

- Percentage errors: Error reading × 100%, e.g. 9.84 ± 0.6 = 9.84 ± 6%

- Absolute uncertainty: Highest reading – lowest reading and divide by 2, e.g. using the above set of readings:
  Error = (2.543 – 2.539) ÷ 2 = 0.004 ÷ 2 = ±0.002

- Adding and subtracting: Add errors, e.g. 16.54 ± 0.03 – 12.86 ± 0.06 = 3.68 ± 0.09

- Multiplying and dividing: Add percentage errors,
  e.g. (44.95 ± 2) ÷ (12.3 ± 1)
  = (44.95 ± 4%) ÷ (12.3 ± 8%)
  = (3.65 ± 12%)
  = 1.44 ± 0.4

Questions

1. Calculate the mean and the random error of the following set of readings: 98.7, 97.9, 98.4, 99.0, 98.6

2. Calculate the mean and the random error of the following: 0.89, 0.90, 0.86, 0.85, 0.91

3. Calculate the mean and the absolute uncertainty of: 1005, 1001, 999, 995, 1000

4. Calculate the mean and the absolute uncertainty of the following: 0.073, 0.072, 0.073, 0.069, 0.075, 0.071

5. Calculate the mean and absolute uncertainty and percentage error of the following: 102, 104, 99, 99, 96

6. Calculate the mean and absolute uncertainty and percentage error of: 6.7, 7.0, 6.8, 6.9, 7.1, 6.7, 6.6, 7.1

7. Add the following: (24.9 ± 0.7) + (16.2 ± 0.2)

8. Subtract the following: (0.721 ± 0.004) – (0.650 ± 0.003)

9. Multiply the following: (22.4 ± 5%) × (6.7 ± 2%). Express your answer with a percentage error.

10. Calculate the following: (24.0 ± 2) ÷ (8.0 ± 1). Express you answer as a percentage error, then convert this percentage error to an absolute error.

Notes

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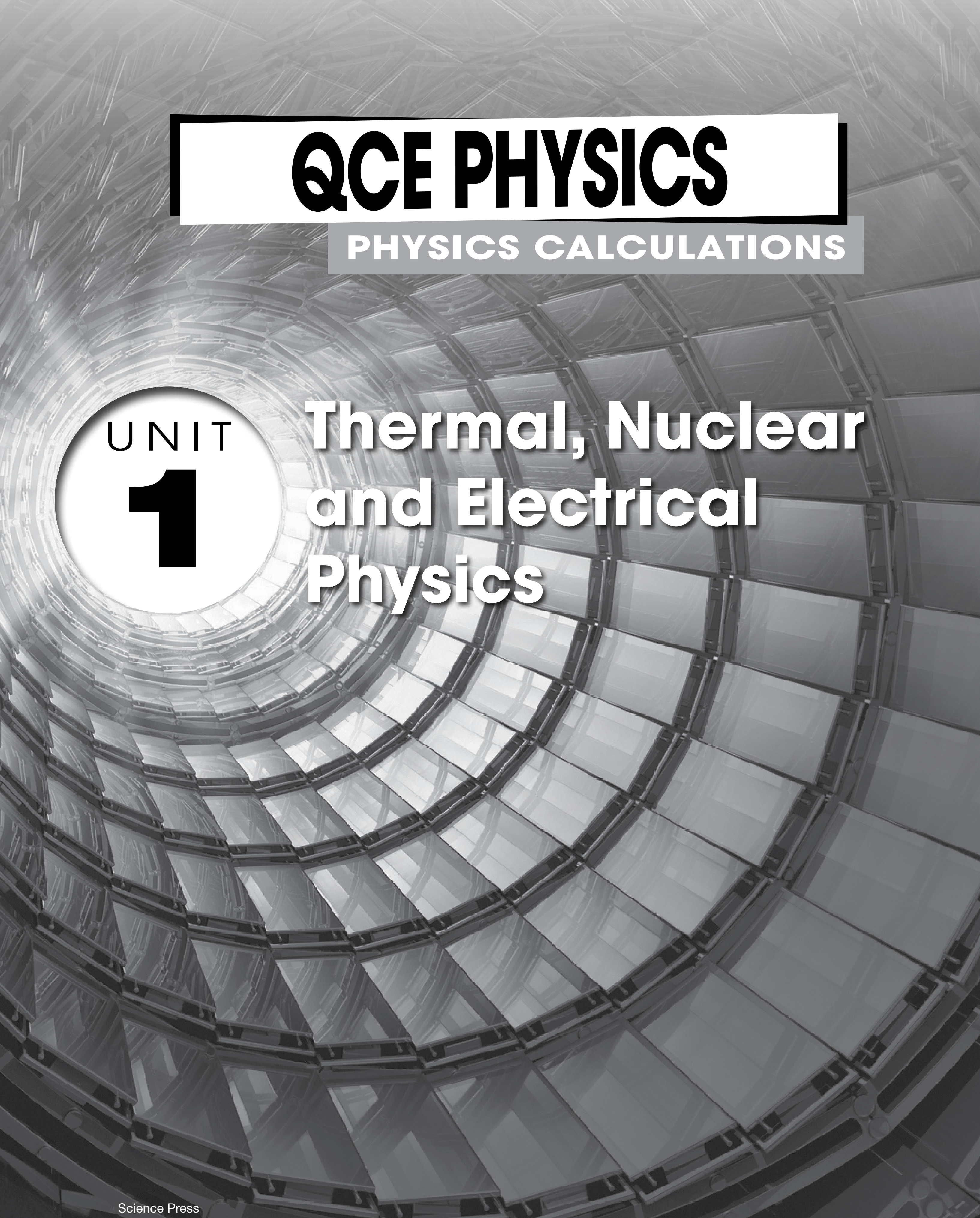

QCE PHYSICS

PHYSICS CALCULATIONS

UNIT 1 Thermal, Nuclear and Electrical Physics

Notes

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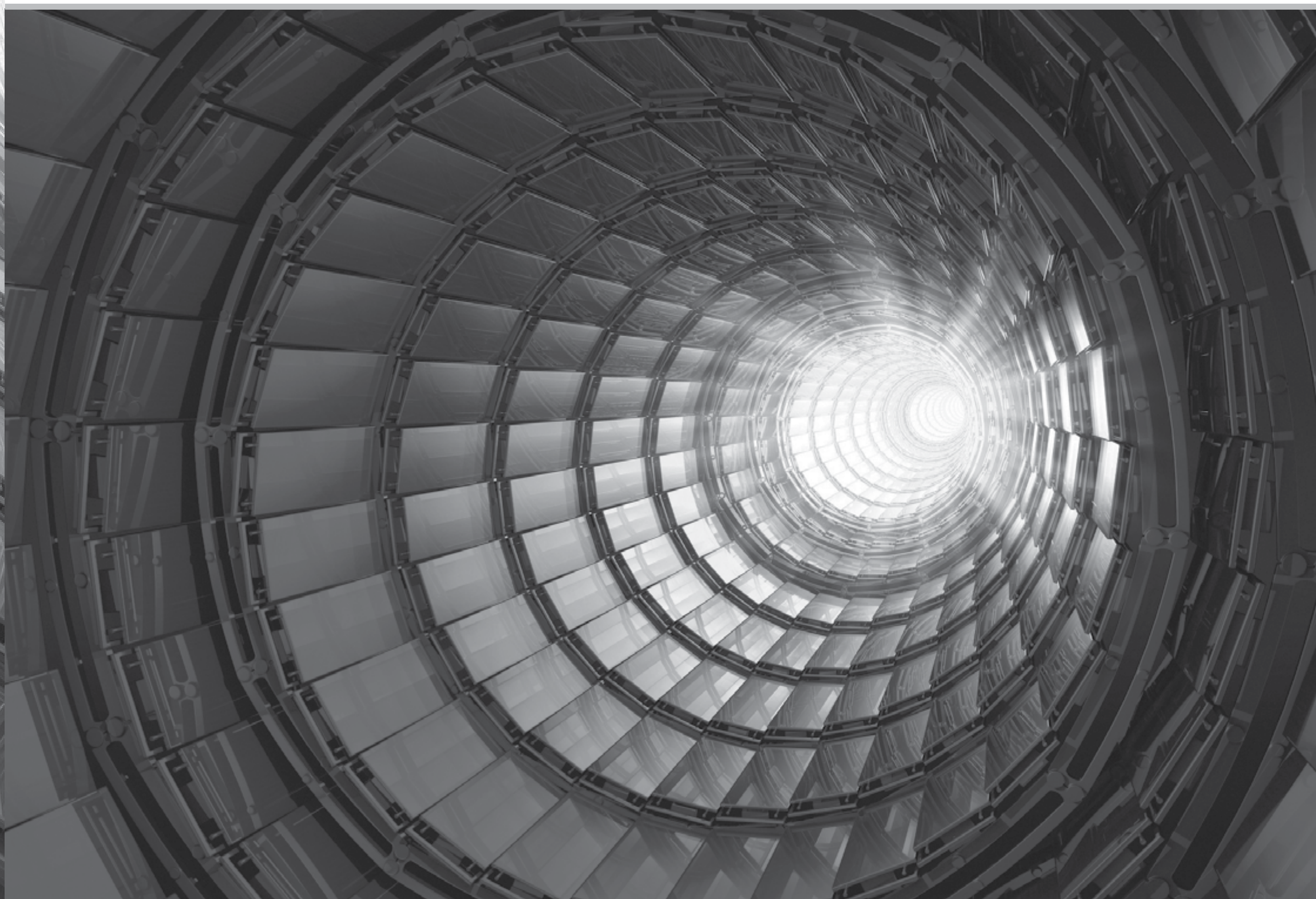
Topic 1: Heating Processes



3. Temperature

Fixed points	Melting point of ice	Melting point of water
Celsius	0°C	100°C
Fahrenheit	32°F	212°F
Absolute (Kelvin)	273.15 K	373.15 K

Comparative sizes: 1 kelvin = 1 Celsius degree = 1.8 Fahrenheit degree

Changing scales: Celsius to kelvins: add 273.15 (or 273 approximately)

Kelvins to Celsius: subtrtact 273.15 (or 273 approximately)

Celsius Fahrenheit or vice versa: $\frac{F - 32}{C} = \frac{9}{5}$

Thus $F = \frac{9C - 32}{5}$ and $C = \frac{5(F - 32)}{9}$

Note that in the exercises which follow in this book, changes of temperatures are quoted in kelvins (K) rather than in Celsius degrees whereas temperatures are quoted in degrees Celsius (°C).

Questions

1. Change 35°C to absolute temperature.

2. Change 300K to Celsius temperature.

3. Change –67°C to absolute temperature.

4. Change 76°F to Celsius temperature.

5. Change –89°F to absolute temperature.

6. Change 56K to Fahrenheit temperature.

7. The temperature of the visible surface of the Sun is 5 778 K. Many popular science magazines like to report temperatures in Fahrenheit degrees. Convert its temperature to degrees Fahrenheit.

8. Iron melts at 1 538°C whereas mercury melts at –38.83°C. Change these temperatures to kelvins.

9. The normal temperature of the human body on my old thermometer is 98.6°F. Convert this temperature to Celsius degrees.

10. The normal temperature for a dog ranges from 101 to 102.5 degrees Fahrenheit. Convert these readings to Celsius readings.

11. According to the Weather Bureau, the forecast temperature for the city of New York one day in January was 1°F. Canadians living in Toronto, just above New York State use Celsius temperature readings. Change 1°F to degrees Celsius for the benefit of New York's northern neighbours.

4. Specific Heat Capacity

$Q = mc\Delta T$	Q	= heat transferred to or from an object (joules) J
	m	= mass of object (kg)
	c	= specific heat capacity of the object (J kg^{-1} K^{-1} or J kg^{-1} °C^{-1})
	ΔT	= temperature change
	η	= efficiency = (energy output / energy input) × 100%

Questions

Note that in these exercises changes of temperatures are quoted in kelvins (K) rather than in Celsius degrees whereas temperatures are quoted in degrees Celsius (°C).

1. Calculate the amount of heat needed to raise the temperature of 0.500 kg of water by 35 K given that the specific heat capacity of water is 4.18 kJ kg^{-1} K^{-1}.

2. 0.650 J of energy was required to raise the temperature of a sample of aluminium from 20°C to 45°C. Calculate the mass of the aluminium sample. (c = 0.900 kJ kg^{-1} K^{-1}.)

3. Calculate the specific heat capacity of copper given that 2.34 kJ raises the temperature of 0.200 kg of copper from 15°C to 45°C.

4. Porcelain has a specific heat capacity of 0.840 kJ kg^{-1} K^{-1}. A porcelain cup of mass 0.250 kg holds 0.250 kg of water. Calculate the amount of heat energy required to raise the temperature of a cupful of water from 20°C to 100°C. (c of porcelain = 0.897 kJ kg^{-1} K^{-1} and c of water = 4.18 kJ kg^{-1} K^{-1}.)

5. A sample of 0.480 kg of ethanol lost 6.00 kJ of heat. If the final temperature after cooling was 7.5°C calculate the initial temperature. (c of ethanol = 1.42 kJ kg^{-1} K^{-1}.)

6. For each kilojoule of heat supplied by a particular source of heat, 0.25 kJ is 'wasted' (not used to heat the sample). Calculate the amount of heat which would have to be supplied to 0.750 kg of lead to raise its temperature from 25°C to 200°C. (c of lead = 0.129 kJ kg^{-1} K^{-1}.)

7. An electric kettle supplies heat energy at the rate of 1000 W (1000 joules per second). How long would it take to bring 200 g of water from 18ºC to 100ºC. The specific heat capacity of water is 4.18 kJ kg^{-1} K^{-1}.

8. 100 g of cast iron was heated from 20ºC to 100ºC in 3 minutes. Given that the specific heat capacity of cast iron is 0.450 kJ kg^{-1} K^{-1} calculate the rate at which heat energy was being supplied to heat the iron. (Answer in watts.)

9. The SI unit for measuring heat energy is the kilojoule (kJ) but in some parts of the world, food energy is measured in calories. 1 calorie is equal to 4.18 kJ. You may sometimes find food labels expressing the energy in calories. A popular energy bar sold in America is listed as providing 140 calories of food energy. Convert this to kJ.

10. Hank, recently arrived from overseas wants to know the food energy in a snack bar but it is listed as 58 kJ. Convert this to calories with which Hank is more familiar.

5. Latent Heat Capacity

$Q = mL$

Q = heat transferred to or from the object (kilojoules) kJ

L_f = latent heat of fusion kJ kg^{-1}

L_v = latent heat of vaporisation

Questions

1. Calculate how much energy would be needed to melt 1.2 kg of lead (L_f of lead = 23.0 kJ kg^{-1}).

2. The latent heat of vaporisation of water is 2264.7 kJ kg^{-1}. Calculate the energy required to boil 1.5 kg of water at 100°C.

3. Calculate the mass of alcohol which could be vaporised by 1500 kJ of energy (L_v of alcohol = 108 kJ kg^{-1}).

4. The latent heat of fusion of mercury is 11.4 kJ kg^{-1}. Calculate what mass of mercury could be melted from a solid to a liquid by 2 kJ of heat.

5. Calculate the latent heat of fusion of aluminium if 2.5 kg of aluminium needs 992.5 kJ of energy to melt it.

6. Calculate the latent heat of vaporisation of copper if 600 kJ of heat energy will melt 2.04 kg of the metal.

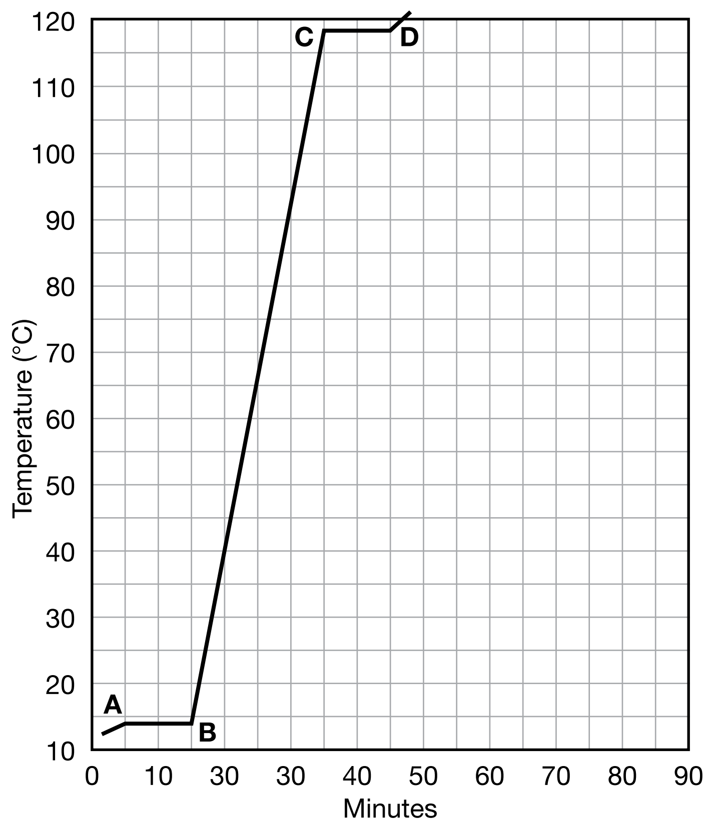
7. 100 g of water is heated from 20°C to 100°C and then turned into vapour (boiled). Calculate the amount of heat energy used. (c = 4.12 kJ kg^{-1} K^{-1}, L_v = 2264.7 kJ kg^{-1})

8. 4.5 kg of iron which had a temperature of 18°C was heated to its melting point, 1204°C and then melted completely. Calculate the amount of heat energy expended. (c = 0.460 kJ kg^{-1} K^{-1}, L_f = 247 kJ kg^{-1})

9. In a science demonstration, 10 g of solid nitrogen at its melting point (–210°C) was thrown onto the floor which was at room temperature of 23°C. The nitrogen very quickly melted, warmed to its boiling point (–196°C) and vaporised. Calculate the amount of energy required to do this. (L_f = 199 kJ kg^{-1}, L_v = 25.8 kJ kg^{-1}, c_{liquid} = 1.04 kJ kg^{-1} K^{-1})

10. 100 g of water at 25°C was heated in an electric jug which was supplying 0.8 kW of heat. The safety switch which turns the electricity off when the water boils was defective and the water boiled away. Calculate the time taken.

11. The graph represents the temperature of 1 kg of ethanoic acid, originally frozen while being heated at the rate of 20 kJ per minute.



(a) Explain what is happening between A and B on the timeline.

(b) Explain what is happening between B and C on the timeline.

(c) Explain what is happening between C and D on the timeline.

(d) What is the melting point of solid ethanoic acid?

(e) What is the boiling point of liquid ethanoic acid?

(f) Calculate, from the graph the latent heat of fusion of the acid.

(g) Calculate, from the graph the latent heat of vaporisation of the acid.

(h) Calculate, from the graph the specific heat capacity of the acid.

6. Thermal Equilibrium

When materials at different temperatures are mixed, the final temperature attained lies partway between the initial temperatures of the two materials.

The heat lost by the hotter material will be equal to the heat gained by the cooler material.

$$m_1 c_1 \Delta T_1 = m_2 c_2 \Delta T_2$$

$$m_1 c_1 \Delta T_1 = m_2 L$$

m = mass of material

c = specific heat capacity

L = latent heat

ΔT = change of temperature

Subscript 1 applies to the hotter

Subscript 2 applies to the cooler

Questions

1. 500 g of water at 90°C was mixed with 300 g of water at 20°C. Calculate the final temperature. (c = 4.18 kJ kg^{-1} K^{-1})

2. 1 kg of ethanol at a temperature of 80°C was diluted by 0.5 kg of water at 15°C. Calculate what the final temperature would be. ($c_{ethanol}$ = 2.5 kJ kg^{-1} K^{-1})

3. Calculate the amount of water at 20°C which would be needed to cool to 30°C a piece of cast iron of mass 0.5 kg at an initial temperature of 150°C. ($c_{cast\ iron}$ = 0.110 kJ kg^{-1} K^{-1})

4. A piece of aluminium at a temperature of 200°C was plunged into 500 g of oil at a temperature of 25°C. The final temperature of the aluminium and the oil was 40°C. Calculate the mass of the aluminium. (c_{Al} = 0.900 kJ kg^{-1} K^{-1}, c_{oil} = 2.0 kJ kg^{-1} K^{-1})

5. A copper rod of mass 500 g at a temperature of 300°C was plunged into 1000 g of turpentine at a temperature of 25°C. The final temperature was 52°C. Calculate the specific heat capacity of turpentine. (c_{Cu} = 0.386 kJ kg^{-1} K^{-1})

6. Michael made a 250 mL cup of coffee with boiling hot water (100°C). He wanted to cool the coffee to a drinkable 55°C by adding ice cubes. Calculate how many ice cubes, each of mass 10 g at 0°C would he need. Assume that the specific heat capacity of the coffee is the same as that of water (4.18 kJ kg^{-1} K^{-1}). The latent heat of fusion of ice is 334 kJ kg^{-1}.

QCE PHYSICS

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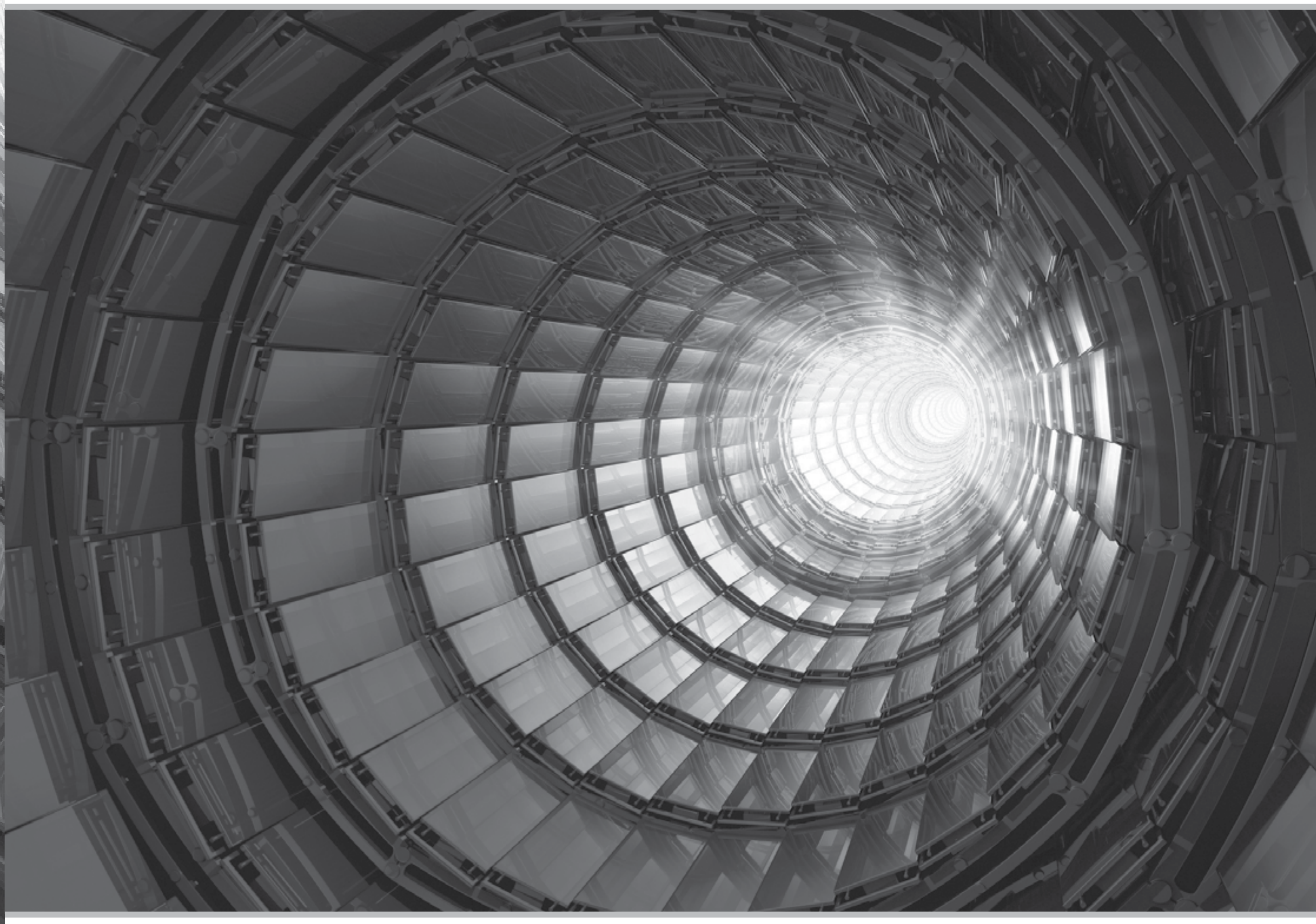
Answers



1 Physics Basics

1. $1 \div 10^{-3} = 10^3$
2. $1 \times 10^3 \div 10^{-2} = 10^5$
3. $1 \times 10^{-3} \div 10^{-6} = 10^3$
4. $1 \times 10^{-3} \div 1 = 10^{-3}$
5. $1 \times 10^3 \div 10^6 = 10^{-3}$
6. $1 \times 10^{-6} \div 10^3 = 10^{-9}$
7. $1 \times 10^{-3} \div 10^{-9} = 10^6$
8. $1 \times 100^3 \div 10^9 = 10^{-6}$
9. $1 \times 10^{-2} \div 10^{-12} = 10^{10}$
10. $1 \times 10^{12} \div 10^{-18} = 10^{30}$
11. $7505.23 \approx 7500.00 = 7.5 \times 10^3$
12. $0.003425 \approx 0.0034 = 3.4 \times 10^{-3}$
13. $70.2 \times 34.2 = 2400.84 \approx 2400 = 2.4 \times 10^3$
14. $1578.3 + 0.400 = 1578.700 \approx 1600 = 1.6 \times 10^3$
15. $\frac{0.600 \times 7020.0960}{0.0960} = 43875\ 6 \approx 44000 = 4.4 \times 10^4$
16. $\frac{1.53}{42.89 \times 8.4} = 4.246744163 \times 10^{-3} = 4.2 \times 10^{-3}$
17. $\frac{0.8235 \times 445\ 7}{76.9 \times 0.00930} = 513.21217 \approx 510 = 5.1 \times 10^2$
18. $20.4 \times 10^{-7} = 2.04 \times 10^1 \times 10^{-7} \approx 2.0 \times 10^{-6}$
19. $134 \times 10^8 = 1.34 \times 10^2 \times 10^8 \approx 1.3 \times 10^{10}$
20. $\frac{(2.4 \times 10^{-3}) \times (5.6 \times 10)^4}{(3.0 \times 10^7)^4} = 1.659259259 \times 10^{-28} \approx 1.7 \times 10^{-28}$
21. $8.2 \times 10^{-4} \approx 10 \times 10^{-4} = 10^{-3}$
22. $3.5 \times 10^7 \approx 1 \times 10^7 = 10^7$
23. $73.6 = 7.36 \times 10^1 \approx 10 \times 10^1 = 10^2$
24. $0.00901 \approx 0.010 = 10^{-2}$
25. $863.7 \times 10^{-5} = 8.673 \times 10^2 \times 10^{-5} \approx 10 \times 10^2 \times 10^{-5} = 10^{-2}$
26. $0.01673 \times 10^6 = 1.673 \times 10^{-2} \times 10^6 \approx 1 \times 10^4 = 10^4$
27. $3.5 \times 10^6 \times 9.2 \times 10^{-4} = 3220 = 3.220 \times 10^3 \approx 1 \times 10^3 = 10^3$
28. $\frac{7.6 \times 10^{-5}}{1.9 \times 10^4} = 4.0 \times 10^{-9} \approx 1 \times 10^{-9} = 10^{-9}$
29. $24 \times 60 \times 60 = 86400 = 8.64 \times 10^4 \approx 10 \times 10^4 = 10^5$
30. $365.25 \times 24 = 5766 = 8.766 \times 10^3 = 10 \times 10^3 = 10^4$
31. $4.5 \div 10^{-3} = 4.5 \times 10^3$
32. $276 \div 10^{-9} = 2.76 \times 10^{11}$
33. $0.359 \times 10^{-3} \div 10^3 = 3.59 \times 10^{-7}$
34. (a) $0.0038 = 3.8 \times 10^{-3}$
    (b) $2400.84 \approx 2400 = 2.4 \times 10^3$
    (c) $0.018303843 \approx 0.018 = 1.8 \times 10^{-2}$
35. (a) $7.4 \times 10^{-5} \approx 10 \times 10^{-5} = 10^{-4}$
    (b) $2.4 \times 10^3 \times 1.8 \times 10^{-5} = 0.0432$
    $= 4.32 \times 10^{-2} \approx 1.0 \times 10^{-2} = 10^{-2}$
    (c) $\frac{8.64 \times 10^{-7}}{2.95 \times 10^3} = 2.9 \times 10^{-10} \approx 1.0 \times 10^{-10} = 10^{-10}$

2 Errors and Absolute Uncertainty Of the Mean

1.

	Readings	Deviations
	98.7	+0.02
	97.9	−0.06
	98.4	−0.01
	99.0	+0.05
	98.6	+0.01
Sum	489.6	
Mean	98.5	
Value	98.5 ± 0.06	

2.

	Readings	Deviations
	0.89	+0.01
	0.90	+0.02
	0.86	−0.02
	0.85	−0.03
	0.91	+0.03
Sum	4.41	
Mean	0.88	
Value	0.88 ± 0.03	

3. Mean = 5000 ÷ 5 = 1000
   Error = ± (1005 – 999) ÷ 2 = ±3
4. Mean = 0.432 ÷ 6 = 72
   Error = ± (0.075 – 0.069) ÷ 2 = ±0.003
5. Mean = 500 ÷ 5 = 100
   Error = ± (104 – 96) ÷2 = ±4
6. Mean = 44.8 ÷ 7 = 6.4
   Error = ± (6.9 – 5.8) ÷ 2 = ±0.06
   Percentage error = $\frac{0.06}{6.4} \times 100 = \pm 0.9\ \%$