# Answers to self-assessment questions in Chapters 13 to 16

## 13 Relativity

1 805 m, 23 s
3 b $1.8 \times 10^6$ m c 500 m s$^{-1}$
4 a $c$
b $1.1c$
5 $1.2c$
6 $1.3c$
7 $8.85 \times 10^{-12}\,C^2\,N^{-1}\,m^{-2}$, $4\pi \times 10^{-7}$ T m A$^{-1}$
9 a inertial
b inertial
c almost inertial
d not inertial
e almost inertial
10 Rachel, in the rocket, sees the version on the left; Gavin in the gas cloud sees the version on the right.
11 $v\Delta t$
12 $(c^2 + v^2)^{½}$
13 $(c^2 + v^2)^{½}\Delta t$
14 $c\Delta t$
15 $\Delta t = \Delta t'/(1 - v^2/c^2)^{½}$
17 the electron's
18 fixed point
19 yes, the observer travelling with the rod
20 no, neither observer measures proper time
21 laboratory reference frame
22 observer travelling with the rod
23 observer in laboratory reference frame
24 no, neither observer measures proper length
25 a 1.005
b 1.5
c 2.3
d 3.2
27 a 0.00
b $0.494c$
c $0.866c$
d $0.968c$
28 a 1.15
b 12 ly, 12 y
29 82 000 ly
30 410 years
31 2.3, 0.0 m, $4.2 \times 10^{-9}$ s
32 2.6 m, $2.1 \times 10^{-8}$ s
33 a $c$
b $c$
34 $0.94c$
35 $0.98c$
36 $0.79c$
37 $0.70c$
38 $0.9999995c$
39 $c$
40 $-0.17c$
41 0.600 m
42 $4.2 \times 10^{-9}$ s
43 a 0.96 m
b $2.7 \times 10^{-9}$ s
44 a $0.65c$ b $5.9 \times 10^{-7}$ s
c 114 m d $0.65c$
45 680 m
46 a $2.69 \times 10^{-5}$s
b $3.80 \times 10^{-6}$s
c The half-life of muons is only $1.5 \times 10^{-6}$s so these is a significant drop in the muon count rate between 8.00 km altitude and at the Earth's surface. If the drop in muon count rate is consistent with just over 2.5 half-lives this supports relativity; if it is consistent with 18 half-lives it is consistent with Newtonian physics.
48 a

| Event | Coordinates in S (x, ct) | Coordinates in S′ (x′, ct′) |
|---|---|---|
| A | (0, 0) | (0, 0) |
| B | (1, 1) | (0.4, 0.4) |
| C | (1.6, 1.1) | (1,0) |
| D | (2, 1.4) | (1.2, 0) |
| E | (1.1, 1.6) | (0, 1) |
| F | (2, 2.2) | (0.6, 1) |
| G | (2.7, 2.7) | (1, 1) |

b Order of events according to an observer in S: A, B, C, D, E, F, G.

Order of events according to an observer in S′: ACD (simultaneously), B, EFG (simultaneously).

49 a $0.58c$ b 1.2
c 17 years d 17 ly
e 1.2 f S′
g 17 ly/1.2 = 14 ly
50 a $0.90c$
b 2.3
c 0.44 m
d 1.2
54 a $1.60 \times 10^{-19}$ J
b $6.25 \times 10^{18}$ eV
c $9.00 \times 10^{16}$ J
d $5.6 \times 10^{35}$ eV c$^{-2}$
e $1.9 \times 10^{27}$ eV c$^{-1}$
55 32.5 MW
57 a $0.86c$
b $1.9 \times 10^{-8}$ s
c $9.8 \times 10^{-9}$ s
58 $0.999999991c$
59 953 MeV
60 97.8 GeV c$^{-2}$, 96.9 GeV, 97.8 GeV c$^{-1}$
61 61 GeV c$^{-1}$
62 0.05175 c, 193.1 MeV c$^{-1}$
63 $5 \times 10^{19}$ eV c$^{-1}$
64 110 nm
65 100 keV c$^{-1}$
66 511 keV c$^{-1}$
67 a 8 MeV and 542 MeV
b $1.5 \times 10^{-13}$m and $2.3 \times 10^{-15}$m
68 $4.67 \times 10^{-6}$ kg m s$^{-1}$
69 7.09 mm s$^{-2}$
72 a 8.32 kHz
b $7.36 \times 10^{-7}$ m s$^{-1}$
74 a 0.3 m
b 2.1 m
c 550 m
76 Joseph Hafele and Richard Keating
77 $6.2 \times 10^{13}$ m
78 $7.7 \times 10^{9}$ m

## 14 Engineering physics

1 210 N
2 a 5.6 Nm
3 No. The increased torque provided by having one force further from the axis is balanced by having the other force closer to the axis.
5 $\approx 1 \times 10^{47}$ kg m$^2$
6 a $8.1 \times 10^{-6}$ kg m$^2$
b The ball has a constant density.
7 a If the mass of the spokes are considered negligible, it can be approximated to a thin, hollow cylinder.
b $\approx 0.1$ kg m$^2$
8 a 0.50 kg m$^2$
b 2.1%
9 a 36 kg m$^2$
10 a $4.3 \times 10^{-3}$ rad s$^{-1}$
b 24 minutes

11 a $1.4\,rad\,s^{-2}$
b $13\,s$
12 a $26\,rad\,s^{-1}$ b $65\,rad$
c 10 rotations d 38 rotations
13 $7.8\,rad\,s^{-2}$
14 a $314\,rad\,s^{-1}$
b $2.1\,rad\,s^{-2}$
15 $1.2\,kg\,m^2$
16 a $11\,rad\,s^{-2}$
b $9.8 \times 10^{-2}\,kg\,m^2$
17 $0.13\,rad\,s^{-2}$
18 $13.2\,rad\,s^{-1}$
21 a $-2.5\,rad\,s^{-2}$
b $35\,rad$
22 $1.4\,kg$
23 a $0.38\,rad\,s^{-1}$
24 Stars rotate about their axes and if they collapse to a very small dense core (like a neutron star), the law of conservation of angular momentum determines that their angular velocity must increase dramatically. (A full analysis would also need to take into account any loss of mass involved in the collapse.)
25 a about $8\,N\,m\,s$
b about $12\,rad\,s^{-1}$
26 $0.65\,J$
27 a $72\,rad\,s^{-1}$
b $1.9 \times 10^3\,J$
c $E_K = 2.4 \times 10^3\,J$. The two kinetic energies are similar (within 25%).
28 a $95\,cm\,s^{-1}$
b $0.12\,kg\,m^2$
31 a $18\,rad\,s^{-1}$
b The angle of the slope was small enough that the ball was able to roll.
32 72°C
33 Internal energy is the total of the potential and random kinetic energies of all of the molecules in a substance. Temperature is a measure of the average random translational kinetic energy of the molecules. Thermal energy is the non-mechanical transfer of energy from hotter to colder.
34 The most work is done in an isobaric change; the least work is done during an adiabatic change.
35 70 J
36 When molecules collide with the inwardly moving surface they gain kinetic energy. If the change is done quickly there is not enough time for this energy to be dissipated out of the system.
37 a by the gas
b 3000 J
38 a Temperature and internal energy are constant. Pressure decreases.
b The process was isothermal because there was enough time for the energy transferred from the gas during expansion to be replaced from the surroundings.
39 For the same increase in volume, an adiabatic expansion finishes at a lower pressure because the temperature falls.
40 a $2.33 \times 10^5\,Pa$
d $3.7 \times 10^5\,J$
41 $2.45 \times 10^5\,Pa$
42 a AB
b 0.26 mol
c 650 K
d 620 J. This is the work done by the gas in one cycle.
43 e during process d
f 340 J
44
b Increasing inlet temperature or decreasing outlet temperature will have the greatest effects.
c The 'waste' internal energy could be transferred to local homes etc. to help keep them warm in cold weather.
47 Internal energy remains the same; entropy increases.
48 The molecules spread out and become more disordered, so that the entropy increases.
49 It is much easier to mix things up than to separate them because they are more disordered when mixed.
50 Only a very simple process in which no significant amount of energy is dissipated. Perhaps a few swings of a good, simple pendulum.
51 First law – energy cannot be created; second law – energy is always dissipated.
52 about $160\,J\,K^{-1}$
53 a $-70\,J\,K^{-1}$
b greater than $+70\,J\,K^{-1}$
54 $58\,J\,K^{-1}$
55 0.763 m
56 If the tubes were closed, the pressures above the liquid in different tubes would not be the same.
57 30 m
58 a left-hand side
b $9.2 \times 10^2\,kg\,m^{-3}$
c $1.033 \times 10^5\,Pa$
59 $8.15 \times 10^5\,Pa$
61 a 4.8 cm
b $925\,kg\,m^{-3}$
63 Breathing in increases the volume of the body and the weight of the water displaced. This increases the upthrust.
64 Submarines have *ballast tanks*, which can be filled with variable amounts of water and air. In this way the overall weight of the submarine can be changed.
65 rise
66 plimsoll line
67 a 260 N
b 1.1 cm
c 11 N
69 a $1.7 \times 10^2$
b 4.6 m
70 a $53\,cm\,s^{-1}$
b The gas behaves as an ideal fluid and is not compressed.
72 The aerofoil on the car is inverted (compared with that on a plane), so that it creates extra force downwards. This increases friction.
73 a 80 kg
b $35\,m\,s^{-1}$
c The flow is streamlined and the water at the turbine inlet is at atmospheric pressure.
75 a $5.7 \times 10^3\,Pa$
b $360\,cm\,s^{-1}$
c $1.4 \times 10^3\,Pa$
76 Because of the curved shape of the sail, the wind flows faster past the front of the sail. This creates a perpendicular force on the sail from behind (due to the pressure difference). This force has a component in the direction from which the wind is coming.
78 b $210\,m\,s^{-1}$
79 $1400\,kg\,m^{-3}$
80 a $1.3 \times 10^{-6}\,N$
b $130\,m\,s^{-1}$
c Movement is not streamlined at this speed.
82 Stokes's law can only be applied under limited conditions.
83 5000, turbulent
84 $2.4\,m\,s^{-1}$
85 25 times greater than normal air density
86 dimensions, shape, mass, stiffness
87 about 1 Hz
88 a For example: put it in water.
b No, because the physical properties of the tuning fork have not been changed.

89 a 512 Hz, 768 Hz, 1024 Hz etc.
b Increase the tension in the string.
90 The vibrations of the particles of sand tend to make them move from the positions of antinodes to nodes.
91 a 3.4 J
b 31
92 about 35
93 a $E_p = \frac{1}{2}k\Delta x^2$, $T = 2\pi\sqrt{m/k}$
b 0.14 J
c 5
d 1.6 s
94 12.6 (4π)
95 3.6 W
98 Change its mounting (the way it is attached to the car).

# 15 Imaging

1 a 40 cm
b The second lens should be 'fatter' in the middle.
c Both lenses were made from glass of the same refractive index.
2 a 12.5 D
b It is made from a material of lower refractive index.
3 5 cm
4 a converging lenses
b 67 cm
c +57 D
6 0.80 mm
7 a 21
b 52 cm
c 430
8 0.52 rad
9 a The image is 17 mm tall and 13 cm from the lens.
b 1.7
10 a The image is 14 cm tall and 86 cm from the lens.
b 0.71
11 20 cm from the lens
12 13 cm
13 a inverted, diminished, real
b By changing the distance between the lens and where the image is formed.
15 a 22 cm from lens
b −0.5
16 a 22 cm from lens
b −9
17 7.8 cm
18 9.2 D
19 b 4.0 cm
20 b 2.7
21 An upright, virtual image 20 cm from the lens; linear magnification = 5.0.
22 10 cm
23 a 3.1
b away from the object
c decreases
24 12 D
25 0.024 mm
26 a 5.8 cm from the lens
b 4.3
27 a 40 cm
b virtual, upright, $m = 0.8$
28 Combine with a converging lens of known focal length in order to form a real image.
29 3.0
32 The surfaces of more powerful lenses are more curved.
33 7.7 cm
34 The image is real, magnified (3.8cm) and inverted.
36 a upright, virtual, magnified
b concave, 15 cm
c 30 cm
37 The final (inverted and virtual) image is 37 cm in front of the large mirror.
39 a 4.2 mm
b 31
40 a about $6 \times 10^{-5}$ rad
b about $2 \times 10^{-4}$ mm
c The microscope was used in normal adjustment.
42 a +150 D
b The powerful eyepiece lens will produce significant aberrations.
43 a $6.0 \times 10^{-5}$ rad
b $7.2 \times 10^{-5}$ m
c $4.8 \times 10^{-3}$ rad
44 a 86 cm lens
b 41
c It would be brighter and have better resolution, but the same magnification. It may have more aberrations.
45 If a third converging lens is placed between the other two it can be used to invert the first image, producing an upright image for the eyepiece to magnify.
46 372
47 Keeping aberrations to an acceptable level becomes more and more difficult with larger telescopes. Maintaining the precise shape, alignment and mobility of the components becomes more difficult when they are much bigger and heavier.
49 Air will not contaminate the surface of the mirror; less maintenance; the shape will not change under the action of its own weight, strong supporting structure not needed; easier to steer in different directions.
51 82 m
52 $4.1 \times 10^{-4}$ rad
53 13 km
56 Factors include: security of data, speed of data transfer, convenience, flexibility, cost, maintaining the quality of the data transferred.
57 Induced emfs are proportional to the rate of change of magnetic flux. Higher frequencies will produce faster flux changes than low frequencies (all other factors remaining constant).
59 a 38°
b 69°
60 The signals can only have one of two significantly different values. Pulses representing 1s and 0s are still easily distinguished from each other even if they get distorted in transmission or storage.
61 a unchanged
62 a Where there is contact the radiation can cross the boundary and it will not change speed or refract.
b The claddings prevent core fibres touching each other. It has a similar (but lower) refractive index to the core, so that internal reflection occurs at the boundary between the core and the cladding.
63 76°
68 a −3.0 dB
b 90%
69 20 km
70 $6.0 \times 10^{-16}$ W
74 0.10 $cm^{-1}$
75 a 0.19 $cm^{-1}$
b 43%
76 a 6.4 W b $7.31 \times 10^{14}$
c 0.204 $mm^{-1}$ d 3.39 mm
e increases
77 a 5.0 mm
b $1.2 \times 10^{-2}$ $cm^2\,g^{-1}$
78 A constant proportion of X-rays will be absorbed in equal distances because the probability of an X-ray having an interaction that results in absorption remains the same.
79 0.25 cm

80 $2.3 \times 10^{-3}\,mm^{-1}$
83 Because X-rays and gamma rays of the same energy are identical to each other (although they are emitted by different processes).
85 Without scattering, two parts of the film may have an intensity ratio of 4 to 1, but if the film also detects scattered X-rays the intensities may be in a ratio of, for example, (4 + 2) to (1 + 2), which equals 2 to 1.
86 a To increase the sharpness of the image.
b To some extent the X-rays will spread out, be scattered and be absorbed in the air.
89 $1660\,m\,s^{-1}$
90 a $1.5 \times 10^{-6}\,s$
b 18 cm
c No, because the reflected pulse would be received after the emission of another pulse from the probe.
91 b 11%, no
c $0.09994\,W\,cm^{-2}$
d About 0.1%. The poor transmission is due to the low acoustic impedance of air relative to skin. The gel replaces the air between the skin and the transducer.
92 Resolution is limited by diffraction. X-rays have a *much* smaller wavelength than ultrasound and will not be significantly diffracted by the equipment used, or the parts of the body.
93 a The tissue/bone boundary has the greatest difference in acoustic impedances, so that the greatest percentage of waves are reflected there.
b Because the waves travel at different speeds in different media.
c 43 μs
d $1.59 \times 10^{6}\,kg\,m^{-2}s^{-1}$
94 a In order to achieve maximum transmission of the signal, the impedances on either side of a boundary need to as close as possible in value.
b If the acoustic impedance of the gel was the same as for skin ($1.99 \times 10^{6}\,kg\,m^{-2}\,s^{-1}$), then there would be no significant reflection at that boundary, but the transmission of the waves from the probe to the gel also needs to be considered. Typical gels have $z \approx 2.5 \times 10^{6}\,kg\,m^{-2}\,s^{-1}$.
95 a 40%
b 15%
96 a Ultrasound waves will not penetrate the skull very well. The structure in the brain has small details that will not be resolvable with ultrasound.
b X-rays may harm the baby; ultrasound is able to identify slight differences in soft tissues.
98 Very few ultrasonic waves will penetrate lungs containing air because of the mismatch of acoustic impedances.

# 16 Astrophysics

1 a Earth: $5.5 \times 10^{3}\,kg\,m^{-3}$; Jupiter: $1.4 \times 10^{3}\,kg\,m^{-3}$
b Jupiter is a gaseous planet. Earth is mainly molten, with a solid crust and core.
2 a $3.0 \times 10^{4}\,m\,s^{-1}$
b Mercury's speed is 1.6 times greater than the Earth's speed.
3 a 110 y
b Almost certainly not visible (it would have to be much larger than Jupiter to be seen at that distance).
4 a Mercury, $3.3 \times 10^{23}\,kg$
b By definition a planet must have 'cleared the neighborhood of its orbit'. There are other (less well-known) objects with similar size and mass to Pluto orbiting at about the same distance from the Sun, all of which may affect each other's motions.
5 Jupiter, $1.4 \times 10^{7}\,m$
6 Mercury, 0.39 AU; Uranus, 19 AU
7 a $9 \times 10^{23}\,km$
b $3 \times 10^{10}\,pc$
8 a 4.2 ly
b 3100 km
9 a 0.01 ly
b about 4 km
10 $5.0 \times 10^{2}\,s$
11 a i About 8 months (using data from Table 18.1) and assuming that the planets are at their closest.
ii About 300 000 years
12 $10^{27}$
14 Because 5 ly is considered to be a more manageable number than the equivalent 300 000 AU. The AU is more suited to planetary systems.
15 a $1/3600 = 2.8 \times 10^{-4}$°
b $4.8 \times 10^{-6}\,rad$
16 a 1.8 pc
b $5.6 \times 10^{16}\,m$
c 5.9 ly
17 a 0.0125 arc-seconds
b 0.41 arc-seconds
c 0.375 arc-seconds
18 $3.5 \times 10^{17}\,m$
19 $3.8 \times 10^{27}\,W$
20 $1.5 \times 10^{11}\,m$
21 $L_A/L_B = 130$
22 $7.6 \times 10^{5}$ photons every second
23 $3.2 \times 10^{26}\,W$
24 a $8.1 \times 10^{19}\,m^2$
b $2.5 \times 10^{9}\,m$
25 $1.8 \times 10^{4}\,K$
26 $9.5 \times 10^{-10}\,W\,m^{-2}$
27 $2.8 \times 10^{14}\,km$
28 100/1
29 The star has a radius 2.2 times greater than the Sun.
30 $5.1 \times 10^{-7}\,m$ (green)
31 a 4500 K
b $1.6 \times 10^{22}\,m^2$
c $3.6 \times 10^{10}\,m$
32 a $3.5 \times 10^{-7}\,m$
b $1.0 \times 10^{28}\,W$
c $7.2 \times 10^{-9}\,W\,m^{-2}$
33 $3.6 \times 10^{-7}\,m$
35 $7 \times 10^{9}\,m$
36 1.9:1
37 a $1.1 \times 10^{29}\,W$
b It is a main-sequence star.
c Sun
d 12 000 K
e The radius is approximately double.
38 The supergiant is about $10^4$ times larger
39 a $1.7 \times 10^{30}\,W$
b $1.3 \times 10^{-17}\,W\,m^{-2}$
40 a $2.3 \times 10^{30}\,W$
b about 20 days
41 The luminosities of different supernovae (of the same type) are always the same.
47 a 0.0073
b 0.10
48 $6.1 \times 10^{7}\,km\,h^{-1}$

49 The red-shift is 13 nm and the received wavelength is 423 nm.

50 $5.87 \times 10^{16}$ Hz

52 5300 km $s^{-1}$

53 43 Mpc

54 100 Mpc

55 a $3.8 \times 10^4$ km $s^{-1}$

b 550 Mpc

56 1 The red-shifts of the radiation received from receding galaxies indicates that their speed is proportional to their distance away.

2 The average temperature of a universe that started with a Big Bang would now be 2.76 K; radiation characteristic of this temperature is detected coming from all directions.

57 Hydrogen, because it is the most common element in the universe.

59 a decrease

b increase

60 a A source of radiation of known luminosity, which can be used to determine its distance from Earth.

b The uncertainties associated with other methods are too large when dealing with very distant galaxies.

61 The 'Big Crunch'

62 a 0.072

b 0.93

63 a $3.3 \times 10^{34}$ kg

b i The gas molecules have greater average kinetic energy and therefore exert a greater pressure.

ii 1.4

64 a 3200 $L_\odot$

b 0.82 $M_\odot$

65 a 0.76 $M_\odot$

b $5.3 \times 10^6$ y

66 a $1.7 \times 10^{19}$ kg

b $2.2 \times 10^{-10}$%

68 hydrogen, helium, carbon, oxygen and traces of other light elements

69 The fusion of elements only results in a more stable nucleus (and releases energy) if the product has a nucleon number of 62 or less.

74 a The Earth is not near the centre of the Milky Way, and when we look towards the centre there are more stars to be seen than when we look out of the galaxy.

b What we can see with only our eyes is an incredibly tiny part of the universe, so we are not making observations on the cosmic scale.

75 Because all space is expanding; no space is contracting.

77 The most distant galaxies have the greatest recession speeds and this simplified equation cannot be used if the recession speed approaches the speed of light.

78 The mass and volume of the universe are unknown (although we can estimate values for the *observable* universe).

79 The air is about $10^{26}$ times denser.

82 $3 \times 10^{54}$ kg

83 about 21% greater

85 a $8.1 \times 10^5$ m $s^{-1}$

b The star was moving directly towards or away from Earth at some point in its rotation.

c $2.6 \times 10^{-17}$ kg $m^{-3}$

87 2.8