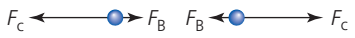
# Answers to examination questions in Chapters 13 to 16

## 13 Relativity

### Paper 3

1 a


b




c In Newtonian physics a star that is moving away from us should emit light that is travelling slower than the speed of light in a vacuum. A star that is moving towards us should emit light that is travelling faster than the speed of light in a vacuum.
The only classical alternative is that light travels through a medium called the ether but the experimental evidence suggests that this does not exist.

2 a A coordinate system/set of rulers/clocks in which measurements of distance/position and time can be made.

b i 1.25 $c$

ii 1.25$c$/(1 + 0.25) shows that fraction = $c$

c Light travels at same speed for both observers. During transit time Officer Sylvester moves towards point of emission at front/away from point of emission at back. Light from front arrives first as distance is less/light from back arrives later as distance is more. Officer Sylvester observes the front lamp flashes first.

*or*

Time between lights arriving at Speedy is zero (according to Speedy) – (this is a proper time) so Sylvester (indeed all inertial observers) sees lights reaching Speedy simultaneously. Front lamp moving away from Speedy (according to Sylvester). Speed of light constant for all observers. Light from front lamp has to travel further to reach Speedy so must have flashed first (according to Sylvester).

d i The two events occur at the same place (in the same frame of reference)/shortest measured time.

ii $1.39 \times 10^{-8}$ s

3 a i (A reference frame) in which Newton's first law holds true/that is not accelerating/that is moving with constant velocity.

ii The speed of light in a vacuum/free space is the same for all inertial observers.

b Signal from switch travels at same speed c to each lamp; but during signal transfer $C_1$ moves closer to/$C_2$ moves away from source of signal. Since speed of light is independent of speed of source, signal reaches $C_1$ before $C_2$/$C_2$ after $C_1$. According to Vladimir $C_1$ registers arrival of signal before $C_2$/$C_2$ registers arrival of signal after $C_1$.

c i 1.4 m

ii Natasha. Proper length is defined as the length of the object measured by the observer at rest with respect to the object.

d i On the return of the travelling twin according to the twin on Earth the travelling twin will have aged very little compared with himself/herself. However, since time dilation is symmetric it could be the twin on Earth who has done the least aging. The experiment suggests that it is the travelling twin who ages the least.

ii Because of the accelerations undergone by the travelling twin the situation is not symmetric/the travelling twin is not in the same inertial frame of reference/changes inertial frame of reference.

e i 890 m

ii 3200 m

f Using the laboratory half-life, most of the muons would have decayed before reaching Earth. However, many muons are detected at the surface, showing that the half-life is dilated/to the muons the distance travelled is contracted.

4 a S′ (1 mark)

b S′. This observer records the two events to occur in the same place.

c The spacetime interval between the two events is the same for both observers.
$(\Delta s)^2 = c^2(\Delta t)^2 - (\Delta x)^2 = c^2(\Delta t')^2 - (\Delta x')^2$
But $\Delta x' = 0$ while $\Delta x \neq 0$ so $\Delta t' \neq \Delta t$

d $\tan 15° \times c = 0.268c$

e 2.1 μs

f The angle of the photon worldlines is 45°. They start from Event 2 and are drawn at 90° to each other.

5 a Spacetime is the unification of the dimensions of space and time into one concept since neither is independent of the other in relativity.

b Events 0 and 1 are simultaneous in reference frame B, but are not simultaneous in reference frame A. This is because the events do not occur in the same place, and since the two reference frames are in relative motion they will observe the times that events occur differently.

c 0.42$c$

d 0.14$c$. According to A this is in the same direction as observer B/positive sign.

e The worldline drawn as a straight line from the origin and at close to 10° to the $ct$-axis.

6 a $v = 0.653c$

b $p$ = 809 MeV. The protons are then accelerated in two beams travelling in opposite directions around the ring and are accelerated up to a speed of 0.97$c$ before colliding.

c The worldline oscillates back and forth with constant period and is symmetrical about a vertical line. The gradient of the worldline is never less than 45°.

d $E = 7.71\,\text{GeV}$

e $u' = 0.9995c$

7 a Particle A: the total energy is the rest mass energy. Particle B: the total energy is the rest mass energy plus the kinetic energy.

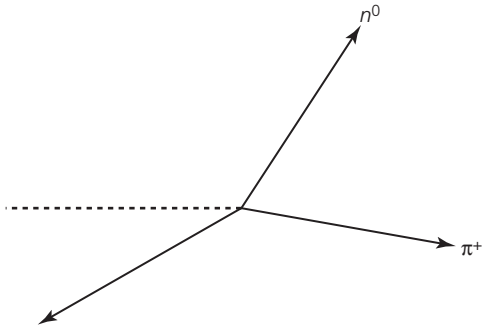
b i $0.999c$

ii $3.35\,\text{GeV}$

c i energy before collision = $6.70\,\text{GeV}$
energy of $p + n = 6.20\,\text{GeV}$

ii $p = 482\,\text{MeV}\,c^{-1}$

d



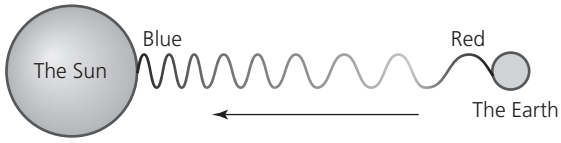

8 a According to relativity the time interval between two events will be longer for observers, in reference frames where the two events occur further apart/are moving faster relative to the events.

b i $1.47 \times 10^{-5}c$

ii It is $1.1 \times 10^{-10}$ greater than 1.

c $9.50 \times 10^{-6}\,\text{s}$

d




Light appears to gain energy as it descends through a gravitational field, causing it to be blue shifted. This is because time slows down in a stronger gravitational field.

e i $1.53 \times 10^{-9}\,\text{s}$ faster per second

ii $1.32 \times 10^{-4}\,\text{s}$ faster per second

9 a i The centre is a single point to which all mass would collapse. The surface is where the escape speed is equal to $c$. Within this surface, mass has 'disappeared' from the universe.

ii The distance from the point of singularity to the event horizon.

iii $R_{SCH} = 3.0 \times 10^{4}\,\text{m}$

iv At $10^{7}\,\text{km}$, space is not warped, so Newtonian physics applies.

b Theory suggests that light is affected by gravitational fields (*plus diagrams or words to explain the formation of two images*).

# 14 Engineering physics

## Paper 3

1 a An object is in rotational equilibrium if it remains stationary or continues to rotate with a constant angular velocity.

b 23 N

c 4.6 s

d The arrow must point to (or from) Q in a clockwise direction. It must have an (approximate) length such as to provide an equal and opposite torque to that provided at P. Its length must be significantly more than twice the length of *F*. The direction is not important, but the vector arrow will be shortest if it points perpendicularly to the line PQ.

2 a The moment of inertia of an object depends on the distribution of mass around the axis of rotation. A hollow sphere must have more mass at a greater distance from the axis (than a solid sphere).

b The spheres both start with the same total gravitational potential energy, which is then transferred to translational and rotational kinetic energies. The solid sphere has the smaller moment of inertia and therefore has the *lesser* rotational kinetic energy. It must have the *greater* translational kinetic energy and speed.

c 30 J

3 a Angular momentum is the product of moment of inertia and angular velocity. ($L = I\omega$)

b i The graph should be approximately sinusoidal in shape, starting at (0,0), showing two complete cycles (four maxima of angular velocity).

ii The pendulum is not an isolated system. It is acted upon by the force of gravity.

c Both $0.76\,\text{rad}\,\text{s}^{-1}$ clockwise

4 a i 0.18 mol

ii $1.9 \times 10^{6}\,\text{Pa}$

b i A smooth, upwardly rising curve going from A to a lower volume; followed by a vertical line to a steeper pressure; then a steeper curve back to A

ii Change b

iii The work done is equal to the area within the cycle drawn on the diagram

5 a i Adiabatic, because the change is too quick to allow the transfer of thermal energy.

ii When gas molecules collide with the inwards-moving piston they gain kinetic energy (and speed), which is measured as an increase in temperature.

b i 120 J

ii The second law states that the entropy of a system must always increase. There will be an entropy decrease in the hot source when it transfers energy, but this must be less than the sum of the two entropy increases: the gain in entropy of the sink as it absorbs energy + the gain in entropy as the engine does useful work.

6 a i $1.0 \times 10^{8}\,\text{Pa}$

ii The pressure due to the atmosphere is very much smaller than the pressure due to the water

(approximately 1:$10^3$) and the question only asks for an estimate.

iii $10^4$ N

b i The pressure acting upwards on the lower surfaces is greater than the pressure acting down on the upper surfaces.

ii $1.5 \times 10^5$ N

c Within the submarine there are sealed tanks that can be filled with variable amounts of water and/or air. In this way the weight of the submarine can be changed to make it greater or less than the upthrust.

7 a i A measure of a fluid's resistance to flow.

ii If the flow is streamlined (laminar, non-turbulent).

b i $3.7 \times 10^{-5}$ N

ii 13 cm $s^{-1}$

c 53 m $s^{-1}$

8 b Graph should have a resonance peak at 0.7 Hz and a smaller peak at 1.4 Hz.

c Similar in shape to **b**, but smaller amplitudes.

d Resonance occurs when energy is transferred from the (infrared) radiation to the molecules of the gas if the frequency of the radiation is equal to a natural frequency at which the masses in the molecules oscillate.

9 a When the amplitudes of oscillations decrease due to resistive forces within systems.

b i under-damping (lightly damped)

ii If the amplitudes of successive peaks all have the same ratio, then the relationship is exponential. Measurements confirm that this ratio ≈ 0.5, showing that an exponential relationship is likely.

c ≈ 9

# 15 Imaging

## Paper 3

1 a Straight rays should be drawn from the line representing the lens (from the two points where the arrows are pointing) through (and beyond) the same focal point on the principal axis. These should be labelled 'red'. Another similar pair of rays, labeled 'blue', should cross the principal axis closer to the lens.

b Red and blue light are focused in different places. This separation of colours and the resulting lack of a clear focus is called chromatic aberration.

c By using a combination of a converging and a diverging lenses made from glasses of different refractive indices.

d i 13 cm from the lens on the same side as the object.

ii 2.7

2 a See Figure 15.23, third diagram.

b i virtual, upright, diminished

ii Anywhere where a wide field of view is required, for example in a driving mirror.

3 a See Figure 15.35.

b at infinity

c See Figure 15.35.

d 2.0 cm from the lens

4 a The angle subtended at an eye by the image, divided by the angle subtended at the eye by the object.

b 3.7

c i 1.0 cm and 4.0 cm

ii 25 D lens

iii 5.0

iv 36

5 a −0.21 dB $km^{-1}$

b Waveguide dispersion occurs because the paths of different rays along the cable are not all exactly the same length. Material dispersion occurs because different wavelengths travel at different speeds in the glass.

c The refractive index of the glass in a graded-index fibre decreases with radial distance from the central axis. This has the effect of refracting the rays into curved paths close to the axis, so that they all travel similar distances.

6 a High-frequency pulses are sent along the coaxial cable, each as the same potential difference between the central copper wire and the surrounding copper mesh, which is earthed.

b Less attenuation; much greater data transfer rates (for cables of similar dimensions); less interference from, or to, signals in other cables; more secure.

7 a The thickness of a medium that reduces the intensity of a parallel beam of X-rays to half.

b 0.305

c A greater fraction will now be transmitted through 6.00 mm. This is because a greater half-value thickness (and smaller attenuation coefficient) means that the same thickness will absorb/scatter less.

d i X-rays are scattered in the patient's body (source too close, too broad or not collimated).

ii An oscillating collimating grid is placed between the patient and the X-ray detector/film.

e A screen placed between the patient (on the grid) and the detector contains fluorescent materials that emit light when X-rays are incident upon them.

8 a Instead of having an X-ray source and detector in fixed positions, they are rotated around the patient, who must lie very still on a bed, which is slowly moved through the beam. The whole process is computer controlled.

b i Images from CT scans have much greater resolution; the X-rays used can pass through bone.

ii Ultrasound is not believed to be any risk to health; images can be observed in real time; equipment is mobile and relatively inexpensive.

9 a between 2 MHz and 20 MHz

b In an A-scan the reflected waves received back at the probe are displayed as varying amplitudes of a p.d.–time graph. B-scans display the information in the form of varying brightness in a two dimensional real-time video image.

c Advantage: less diffraction at higher frequencies produces images with better resolution. Disadvantage: higher-frequency ultrasound waves are more attenuated than those of lower frequencies.

d 1.3

e The answer to **d** shows that there is more attenuation in the bone than in the muscle.

10 a The effect in which a system (which can oscillate) absorbs energy from another external oscillating source that is oscillating at the same frequency as the natural frequency of the system.
b When placed in a strong uniform magnetic field protons in hydrogen atoms precess around the direction of the field (at a rate known as the Larmor frequency). This frequency is in the radio frequency (RF) part of the electromagnetic spectrum. When an external RF magnetic field is applied to the patient, the protons in hydrogen atoms resonate so that their movements become in phase with each other.
c NMR does not involve sending high-energy photons into the patient (which can damage cells).

# 16 Astrophysics

a i nuclear fusion
ii The inwards gravitation pressure is balanced by the outwards radiation and thermal gas pressures.
b i The luminosity of a star is defined as the total power it radiates (in the form of electromagnetic waves).
ii Stars have different masses, resulting in different surface areas and temperatures.
c i The apparent brightness of a star is defined as the intensity (power/receiving area) on Earth.
ii Different luminosities; different distances from Earth.
d i $7.2 \times 10^{-8}\,\text{Wm}^{-2}$
ii Large stars that are relatively cool and therefore yellow/red in colour. They are not on the main sequence and they have a higher luminosity than most other stars, including red giants, because of their size. Red supergiant stars are stars that have finished their lifetime on the main sequence and will explode as supernovae to become neutron stars or black holes, depending on their mass.
iii $8.5 \times 10^{-7}\,\text{m}$

2 a 2.7 K
b The average temperature of the early universe was extremely high. The Big Bang model predicts that, as it has expanded, the average temperature has fallen to the current value. (Alternatively, the wavelength originally emitted has stretched as the universe has expanded.)
c The red shift of spectral lines indicates that distant galaxies are receding at a rate which is proportional to their distance away, so that in the past they must have been closer together.

3 a Since main sequence stars will conform to the quoted equation, showing that $8 \times 10^4 = 25^{3.5}$ confirms that X is a main sequence star.
b The mass of star X is greater than Oppenheimer–Volkoff limit. This means that when it leaves the main sequence it will explode as a supernova and become a black hole.

4 a $3.8 \times 10^6\,\text{m s}^{-1}$
b i Using the variation in luminosity of Cepheid variable stars within the cluster.

5 a Star A, because it has the lowest mass of the three, and only lower-mass stars (less than the Chandrasekhar limit) evolve into white dwarfs.
b The path must go up from A to the red giant region and then down to the white dwarf region.

6 a The cosmic scale factor, $R$ = distance between any two points at a certain time divided by the distance between the same two points at a reference time, usually the present. So that, at the present, $R = 1$, and as the universe expands $R$ increases. For example, at some time in the future if the size of the universe has doubled, $R \rightarrow 2$.
b 1.020
c If the expansion of the universe was linear, $R = 1.000 - 0.020 = 0.980$, but the rate of expansion was less before (because the expansion is accelerating), so a possible value could be, for example, 0.982.

7 a A sudden, unpredictable and very luminous stellar explosion.
b Type Ia supernovae occur when a white dwarf in a binary system attracts enough matter from the other star. Type II supernovae occur after the collapse of a red supergiant.
c Type Ia supernovae occur when the total mass reaches a particular, threshold value. Since this is always the same, the resulting luminosities are always the same, wherever they occur. The distance to a type Ia supernova can be determined from its known luminosity and its apparent brightness observed on Earth.
d At the very high neutron densities and temperatures in supernovae, nuclei can quickly successively capture neutrons and create heavier nuclides before there is enough time for radioactive decay.

8 a A star can only form if the temperature is high enough for fusion to occur. In order to have a high temperature the particles must have sufficient kinetic energy, which they acquire as they lose gravitational potential energy. Particles in nebulae of larger mass have greater gravitational potential energy.
b More massive stars have greater temperatures, so the rate of fusion is higher and the hydrogen is used up much quicker.
c i 0.018 × lifetime of Sun
ii It will evolve into a red giant and then a white dwarf.

9 b See Figure 16.54.
c Stars located at relatively large distances from the centre of the galaxy have rotational velocities much greater than are predicted from calculations involving the observable masses in the galaxy. There must be unobservable mass (dark matter) in the galaxy, particularly towards the edges.
d MACHOs or WIMPs (give a specific example)

10 a The universe is homogeneous and isotropic. This means that all large sections of the universe are essentially similar in structure, and observations made in any direction from any location will all be the same (on the large scale).
b Variations in observations made from Earth are due to objects relatively close to Earth (for example, the structure of our galaxy). These differences are not significant in the enormous scale of the universe.

11 a The theoretical density which would just stop the expansion of the universe after an infinite time.

b $9.2 \times 10^{-27}\,\text{kg}\,\text{m}^{-3}$

c i 5.5 nucleons $\text{m}^{-3}$

ii 57 cm

d i The luminosity of type Ia supernovae is known and when they occur in distant galaxies their distances from Earth can be determined. These distances are greater than would be predicted from a theory of the expansion of the universe at a constant or decreasing rate.

ii The *dark energy* theory suggests that it is present throughout the universe at very low density, providing negative pressure and thus resisting contraction.