Question 1

1. A student used a metre stick to investigate the laws of equilibrium for a set of co-planar forces. He found that the weight of the metre stick was 1.2 N and that its centre of gravity was at the 50.6 cm position.

(*i*) Describe how the student determined (*a*) the centre of gravity and (*b*) the weight of the metre stick.

(*a*) suspended from a thread / balanced on a pivot **[3]**

(*b*) weighing scales / mass balance × *g* **[3]**

(*ii*) Why was it necessary to determine the centre of gravity of the metre stick?

to know where the weight acted / to calculate the moment *[state/imply]* **[4]**

He then applied vertical forces to the metre stick and adjusted them until the metre stick was horizontal and in equilibrium.

(*iii*) Indicate on a labelled diagram how these vertical forces were applied to the metre stick.

weights ***[for downward forces]*** **[2]**

newtonmeters / weights and pulleys ***[for upward forces]*** **[2]**

[–1 if no label present on diagram]

(*iv*) How was it ensured that the metre stick was in equilibrium?

not moving **[4]**

(*v*) What was the principal advantage of ensuring that the metre stick was horizontal?

distances read are perpendicular/correct / trigonometry not needed **[4]**

The following data were recorded.

Position on metre stick	22.5 cm	32.1 cm	72.2 cm	81.3 cm
Force (N)	2.85	2.00	3.00	3.40
Direction	upwards	downwards	downwards	upwards

(*vi*) Calculate the net moment about the 0 cm position.

(2 × 0.321) + (1.2 × 0.506) + (3 × 0.722) = 3.4152 [N m] **[3]**

(2.85 × 0.225) + (3.4 × 0.813) = 3.40545 [N m] **[3]**

3.4152 – 3.40545 = 0.00975 N m **[3]**

[–1 if incorrect fulcrum used]

[accept partial answer for 3, e.g. moment = force × distance, any moment calculated]

(*vii*) Calculate the net vertical force acting on the metre stick.

2.85 + 3.4 – 2 – 3 – 1.2 = 0.05 N [upwards] **[3]**

(*viii*) Explain how these results verify the laws of equilibrium.

net moment ≈ 0

net force ≈ 0 **[4 + 2]**

Question 2

2. In an experiment to verify Boyle's law, a student measured the length *l* of a column of air of fixed mass and uniform diameter, at different values of air pressure *p*.

The following data were recorded.

l (cm)	15.0	20.0	25.0	30.0	35.0	40.0
p (kPa)	360	227	214	178	154	136

(*i*) State Boyle's law.

p is inversely proportional to V / pV = constant

for a fixed mass of gas at constant temperature **[4 + 2]**

(*ii*) Draw a labelled diagram of how the apparatus was arranged in this experiment.

means of measuring p **[3]**

means of measuring V or l **[3]**

means of changing p or V or l **[3]**

[–1 if no label present on diagram]

(*iii*) Why is it necessary for the column of air to have a uniform diameter?

so that V is proportional to l *[state/imply]* **[3]**

(*iv*) Draw a suitable graph to verify Boyle's law.

values for $1/l$ or $1/p$ **[3]**

$1/l$ (cm^{-1})	**0.067**	**0.05**	**0.04**	**0.033**	**0.029**	**0.025**
$1/p$ (kPa^{-1})	**0.0028**	**0.0044**	**0.0047**	**0.0056**	**0.0065**	**0.0074**

labelled axes **[3]**

correct points plotted **[3]**

line of best fit **[3]**

(*v*) Explain how your graph verifies Boyle's law.

straight line through origin **[3]**

One of the data points is inconsistent with the other data points.

(*vi*) Which of the data points is inconsistent with the others?

the second data point, i.e. when l = 20.0 cm **[3]**

(*vii*) How did you treat this data point when you drew your graph?

ignored it **[4]**

Question 3

(*i*) Why did the student first make an approximate measurement of the focal length?

to ensure that the object was placed outside the focal point / so that a real image would be formed / so that the image can be formed on a screen / to check final answer **(6)**

(*ii*) How did the student determine the image positions?

moved a screen until a sharp image was seen **(3)**

(*iii*) Draw a labelled diagram of how the apparatus was arranged.

object, mirror, screen, correct arrangement **(4 × 1)**

(–1 if no diagram present or no label present)

(*iv*) On your diagram, indicate *u* and *v*. **(2 × 3)**

(*v*) Use all of the data to calculate the focal length of the mirror.

formula **(3)**

average value for *f* (≈ 12.1 cm) **(3)**

(–1 if average not found)

Another student carried out this experiment but she measured the image distance *v* for each of **six** different object distances *u*. She then drew a graph and used the graph to calculate the focal length.

(*vi*) Sketch a suitable graph that might have been drawn.

correct x-axis (1/*u*)	**// correct x-axis (*u*)**	**(3)**
correct y-axis (1/*v*)	**// correct y -axis (*v*)**	**(3)**
correct shape of curve (straight line with m = −1)	**// correct shape of curve**	**(3)**

(*vii*) How could this graph be used to calculate the focal length?

intercept(s)	**// point on curve**	**(3)**
= 1/*f*	**// substitute into formula**	**(3)**

Question 4

7. A spring of natural length 150 mm obeys Hooke's law. When an object of mass 200 g is attached to it, the length of the spring increases to 185 mm.

(*i*) State Hooke's law.

extension **// $F = -kx$** **[2]**

proportional to force **// notation** **[2]**

(*ii*) Calculate the elastic constant of the spring.

$F = -kx$ **[2]**

(0.2)(9.8) = k(0.185 – 0.15) **[2]**

k = 56 N m^{-1} **[2]**

The object is pulled down until the spring has a length of 200 mm. The object is then released. It moves with simple harmonic motion.

(*iii*) Calculate the period of oscillation of the object.

$T = 2\pi/\omega$ **[3]**

$\omega = \sqrt{(k/m)}$ or $\omega = \sqrt{280}$ = 16.73 [s^{-1}] **[3]**

$T = 2\pi/16.73$ = 0.375 s **[3]**

(*iv*) Calculate the maximum acceleration of the object.

$a = -\omega^2 x$ **[3]**

$a_{max.}$ = (280)(0.2 – 0.185) = 4.2 m s^{-2} **[3]**

(*v*) What is the speed of the body when it has maximum acceleration?

zero **[3]**

The object is now detached from the spring and attached to the end of a string of fixed length 11 cm. It is made to rotate in a vertical circle with constant angular velocity and with a period of 0.5 s.

Question 5

[accept v = rω as partial answer for 3]

(*vii*) Calculate (*a*) the angular velocity, (*b*) the linear velocity of the object.

(*a*) $T = 2\pi/\omega$ **[3]**

$\omega = 2\pi/0.5 = 12.57 \text{ rad s}^{-1}$ **[3]**

(*b*) $v = 0.11 \times 12.57 = 1.38 \text{ m s}^{-1}$ **[3]**

(*viii*) Calculate the minimum tension in the string.

$F_C = mr\omega^2$ / $F_C = mv^2/r$ **[3]**

$T_{min.} = (0.2 \times 0.11 \times 12.56^2) - (0.2 \times 9.8) = 3.47 - 1.96 = 1.51 \text{ N}$ **[3]**

(*ix*) Draw a labelled diagram of the forces acting on the object when the string has its minimum tension.

weight acting downwards **[2]**

tension acting downwards **[2]**

[–2 for each additional incorrect force; ignore references to centripetal force]

[–1 if no label present on diagram]

14. Answer any **two** of the following parts, (*a*), (*b*), (*c*), (*d*).

(*a*) (*i*) Distinguish between a vector and scalar.

vector has [magnitude and] direction **[2]**

scalar has magnitude only / scalar has no direction **[2]**

(*ii*) Draw a labelled diagram of the arrangement of the apparatus in an experiment to find the resultant of two vectors.

three newtonmeters / three systems of weights and pulleys / three displacements **[3]**

correct arrangement **[3]**

An object is released with an initial velocity of 150 m s^{-1} at an angle of 20° to the horizontal.

(*iii*) Resolve the velocity into horizontal and vertical components.

v_H = 150cos20° [= 141 m s^{-1}] **[3]**

v_V = 150sin20° [= 51.3 m s^{-1}] **[3]**

(*iv*) Calculate the magnitude and direction of the velocity of the object after 8 s.

v_H = 150cos20° [= 141 m s^{-1}] **[4]**

$v = u + at$ / v_V = 51.3 – (9.8 × 8) = –27.1 [m s^{-1}] **[4]**

$|v|$ = 143.5 m s^{-1} **[2]**

10.9° [below the horizontal] **[2]**

Question 7

(*b*) (*i*) What is the Doppler effect?

[apparent] change in frequency [of a wave] **[3]**

due to the [relative] motion between the source and the observer **[3]**

(*ii*) Describe, with the aid of labelled diagrams, how the Doppler effect occurs.

concentric/non-concentric circles drawn [representing wavefronts] **[3]**

motion of wave source towards/away from observer **[3]**

shorter wavelength as source approaches observer [or *vice versa*] **[2]**

therefore greater frequency [or *vice versa*] **[2]**

Pierre drops a child's toy which emits sound of fixed frequency 500 Hz from the top of the Eiffel tower.

(*iii*) Calculate the frequency Pierre observes after 3 seconds.

$v = u + at$ [= (9.8)(3) = 29.4 m s^{-1}]

$f' = fc/(c \pm u)$

f' = 460.2 Hz **[6 + 3 + 3]**

7. (*i*) State Newton's second law of motion.

force is proportional to **// expression** **(3)**

rate of change of momentum **// notation** **(3)**

(allow maximum of 3 marks for F = ma with notation)

(*ii*) State the principle of conservation of momentum.

momentum before interaction = momentum after interaction / formula and notation **(3)**

(*iii*) State the principle of conservation of energy.

energy is not destroyed or created (just converted into a different form) **(3)**

An object A of mass 45 g is travelling at a horizontal speed of 6.2 m s^{-1} when it strikes a resting sphere B of mass 80 g. B hangs vertically at the end of a string, as shown in the diagram. The string is free to move about point *P* which is 1.2 m above the centre of B.

During the collision, A and B are in contact for 25 ms.

After the collision, A recoils with a speed of 1.1 m s^{-1}.

Calculate

(*iv*) the force exerted by B on A,

$F = (mu - mv)/t$ **(3)**

$F = 0.045(6.2 + 1.1)/0.025 = 13.14$ N **(3)**

(*v*) the maximum velocity of B,

$0.045(6.2) = 0.045(-1.1) + 0.08(v)$ **(3)**

$v = 4.11$ m s^{-1} **(3)**

(*vi*) the magnitude and direction of the maximum centripetal force on B,

$F = mv^2/r$ **(3)**

$F = 0.08(4.11)^2/1.2 = 1.12$ N **(3)**

upwards / towards *P* **(2)**

(*vii*) the maximum height gained by B,

$\frac{1}{2}mv^2$ / mgh **(3)**

$h = 0.86$ m **(3)**

(*viii*) the maximum angular displacement of the string.

$\cos\alpha = (1.2 - h)/1.2$ **(3)**

$\alpha = 73.6°$ **(3)**

(*ix*) Draw a labelled diagram to show the force(s) acting on B when it is at its maximum height.

downward arrow, labelled as weight **(3)**

labelled tension arrow in correct direction **(3)**

(–3 for each additional incorrect force)

The string is cut at the instant B is at its maximum height.

(*x*) What is the magnitude and direction of the acceleration of B after the string is cut?

9.8 m s^{-2} **(3)**

downwards **(3)**

(*acceleration due to gravity = 9.8 m s^{-2}*)

9. Ice is used as a coolant due to the high specific heat capacities of ice and water and the high specific latent heat of fusion of ice. It is the principal coolant used in ice packs for insulated picnic boxes, such as the one shown.

(*i*) What is meant by specific heat capacity?

energy to change temperature of 1 kg of a substance **// equation for *c*** **(3)**

by one kelvin **// notation** **(3)**

(*ii*) Why does the high specific latent heat of fusion of ice make it a good coolant?

takes in a lot of energy **(3)**

when melting **(3)**

(*iii*) Suggest two reasons why the walls of a picnic box are made from hollow plastic rather than solid plastic.

better insulator, lower heat capacity, lighter, lower environmental impact **(*any* 2 × 3)**

A picnic box contains food items with an initial temperature of 10.5 °C. The heat capacity of the food is 17.8 kJ K^{-1}. An ice pack that contains 250 g of ice was taken from a freezer held at a temperature of –18 °C and placed in the picnic box. As the temperature of the ice increases and it melts, the temperature of the food decreases.

(*iv*) Calculate the final temperature inside the picnic box when its contents have reached thermal equilibrium.

$mc\Delta\theta$ or $C\Delta\theta$ **(3)**

ml **(3)**

$(0.25 \times 2100 \times 18) + (0.25 \times 330000) + (0.25 \times 4180 \times \theta)$ **(3)**

$= 17800(10.5 - \theta)$ **(3)**

$\theta = 5.04$ °C **(3)**

Freezers and refrigerators operate by use of a heat pump.

(*v*) Draw a labelled diagram of a heat pump.

compressor indicated **(3)**

(expansion) valve indicated **(3)**

correct arrangement of liquid/vapour indicated **(3)**

(*vi*) Explain how a heat pump works.

heat taken in by liquid evaporating **(3)**

heat given out by vapour condensing **(3)**

A student used the apparatus shown below to investigate how heat travels through water.

(*vii*) What observations did the student make?

ice didn't melt / bottom of the tube stayed cold **(4)**

(*viii*) What conclusion could the student have made?

water is a poor conductor (of heat) **(4)**

(*specific heat capacity of ice = 2100 J kg^{-1} K^{-1}; specific heat capacity of water = 4180 J kg^{-1} K^{-1}*)

(*specific latent heat of fusion of ice = 3.3 × 10^5 J kg^{-1}*)

8. The bright outline along the edge of a cloud – the 'silver lining'– is an example of the diffraction of light in nature. Diffraction is a wave phenomenon.

(*i*) What is meant by diffraction?

spreading of a wave **(2)**

through a gap / around an obstacle **(2)**

(*ii*) A diffraction experiment can be used to demonstrate the wave nature of light. Describe such an experiment.

apparatus, method, observation **(3 × 3)**

(*iii*) What is a diffraction grating?

a series of (transparent) gaps **(3)**

(*iv*) Derive the diffraction grating formula, $n\lambda = d\sin\theta$.

d **indicated** **(3)**

θ indicated as angle between straight through and higher order image **(3)**

extra path length = $d\sin\theta$ **(3)**

for constructive interference, extra path length = $n\lambda$ **(3)**

(*v*) Calculate the angular separation between the two 3rd order images formed when blue light of wavelength 442 nm is incident on a diffraction grating of 600 lines per mm.

$d = 1.67 \times 10^{-6}$ (m) **(3)**

$\sin\theta = 3(442 \times 10^{-9})/d = 0.7956$ **(3)**

$2\theta = 105.4°$ **(3)**

(*vi*) Calculate the distance between these images on a screen placed 50 cm from the grating.

$\tan\theta = x/0.5$ **(3)**

$2x = 1.31$ m **(3)**

(*vii*) What changes would be observed if the blue light was replaced with (*a*) with red light, (*b*) with white light?

(*a*) greater angular separation / fewer images **(3)**

(*b*) spectrum (on either side of white zero-order image) **(3)**

(*viii*) Compare the wavelengths of radio waves with those of visible light.

radio waves have longer wavelengths (than visible light) **(3)**

(*ix*) Why are radio waves not observed to undergo diffraction when incident on a diffraction grating of 600 lines per mm?

d **is too small / λ is too big** **(4)**