Question 1

p and V inversely proportional **(4)**
for a fixed mass of gas at constant temperature **(3)**

Question 2

1. **The laws of equilibrium for a set of co-planar forces acting on a metre stick were investigated by a student. She first found the centre of gravity of the metre stick and then determined its weight as 1.3 N.**

How did the student find the centre of gravity of the metre stick?
balanced (horizontally) at a point (fulcrum) / suspended (horizontally) from a string 3

The centre of gravity was at the 50.3 cm mark rather than the mid-point of the metre stick. Explain.
metre stick not uniform / stick chipped / extra material on one end 3

The metre stick was suspended from two spring balances graduated in newtons. The student made use of a set of three weights, which she hung from the metre stick. She adjusted them until the metre stick was at equilibrium. How did the student ensure that the system was at equilibrium?
system not moving 6

Draw a diagram of the experimental arrangement that the student used.
metre stick horizontal 3
metre stick suspended from *two* spring balances with only *three* weights suspended from stick 3

The student recorded the positions of the forces acting on the metre stick and the direction in which each force was acting.

Position of force on metre stick/cm	**11.4**	**21.8**	**30.3**	**65.4**	**80.0**
Force/N	**2.0**	**3.0**	**5.7**	**4.6**	**4.0**
Direction	**downward**	**downward**	**upward**	**upward**	**downward**

Taking the moments of the forces about the mid-point of the metre stick (50 cm mark), use the student's data to calculate
(i) **the total of the clockwise moments**
(ii) **the total of the anti-clockwise moments.**

torque / (turning) moment / M / T = force × distance (= $F \times d$) *(stated or implied)* 3
correct calculation of the moment of any force about any fulcrum 3
moment due to weight of metre stick (= 1.3 × 0.003 = 0.0039 N m) 3
moments (i): (2.0 × 0.386) + (3.0 × 0.282) + (4.6 × 0.154)
= 0.772 + 0.846 + 0.7084 = 2.3264 N m 3
moments (ii): (5.7 × 0.197) + (1.3 × 0.003) + (4.0 × 0.3) = 1.1229 + 0.0039 + 1.2 = 2.3268 N m 3
(–3 for moments taken about any point other than the 50 cm mark)
(–1 for omission of or incorrect units)

Explain how these results verify the laws of equilibrium.
forces up = forces down (= 10.3 N)
total clockwise moments ≈ total anticlockwise moments 4 + 3

Question 3

2. **In an experiment to verify Boyle's law, a student took the set of readings given in the table below.**

X	**120**	**160**	**200**	**240**	**280**	**320**
Y	**52**	**39.1**	**31.1**	**25.9**	**22.2**	**19.6**

What physical quantities do *X* and *Y* represent?
pressure and volume/height/length *(any order)* 2 × 3

Name the units used when measuring these quantities.
e.g. N m^{-2}, kPa, Pa, mbar, atmosphere, cm Hg, torr *etc.* // cm^3 (m^3, mm^3, cm, litre, *etc.*) 2 × 2
(order of units must match the preceding order in the physical quantities)

Draw a labelled diagram of the apparatus that the student used in the experiment.
gas labelled in container with graduations 3
labelled pressure gauge 3
labelled means of adjusting pressure or volume 3

Describe the procedure he used to obtain these readings.
method of changing pressure (e.g. valve) / volume (e.g. piston) 3
read (new) pressure and volume *(stated or implied)* 3

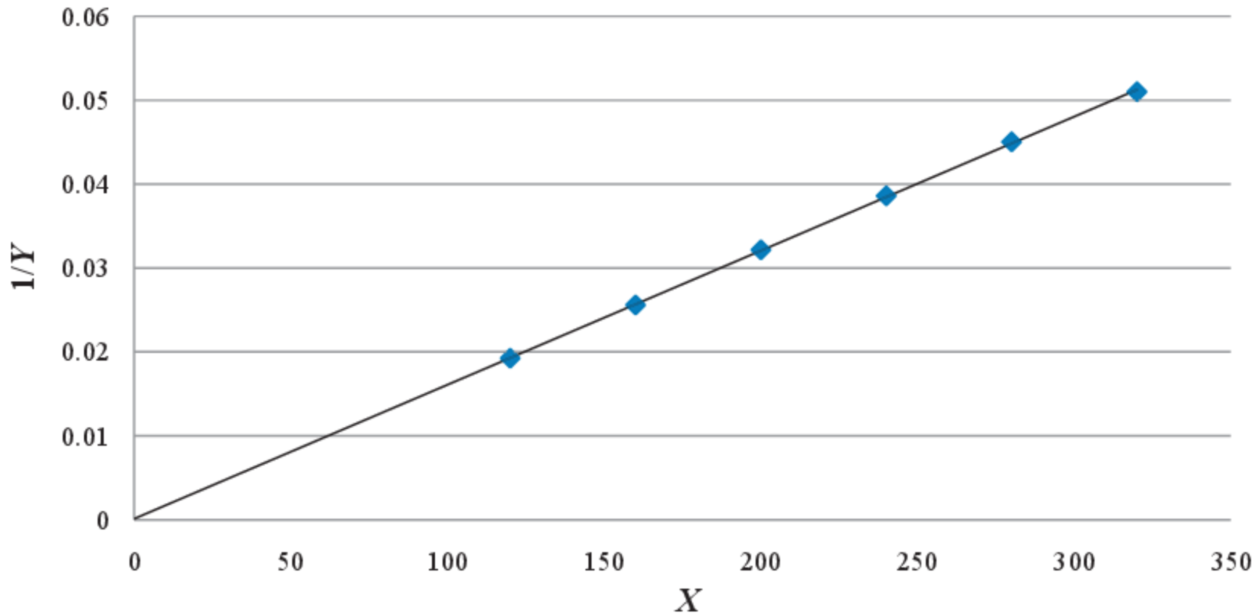
Use the data in the table to draw an appropriate graph on graph paper.
label axes correctly 3
plot six points correctly *(–1 for each incorrectly plotted point)* 6
straight line with good distribution 3

(–1 for inappropriate scale)

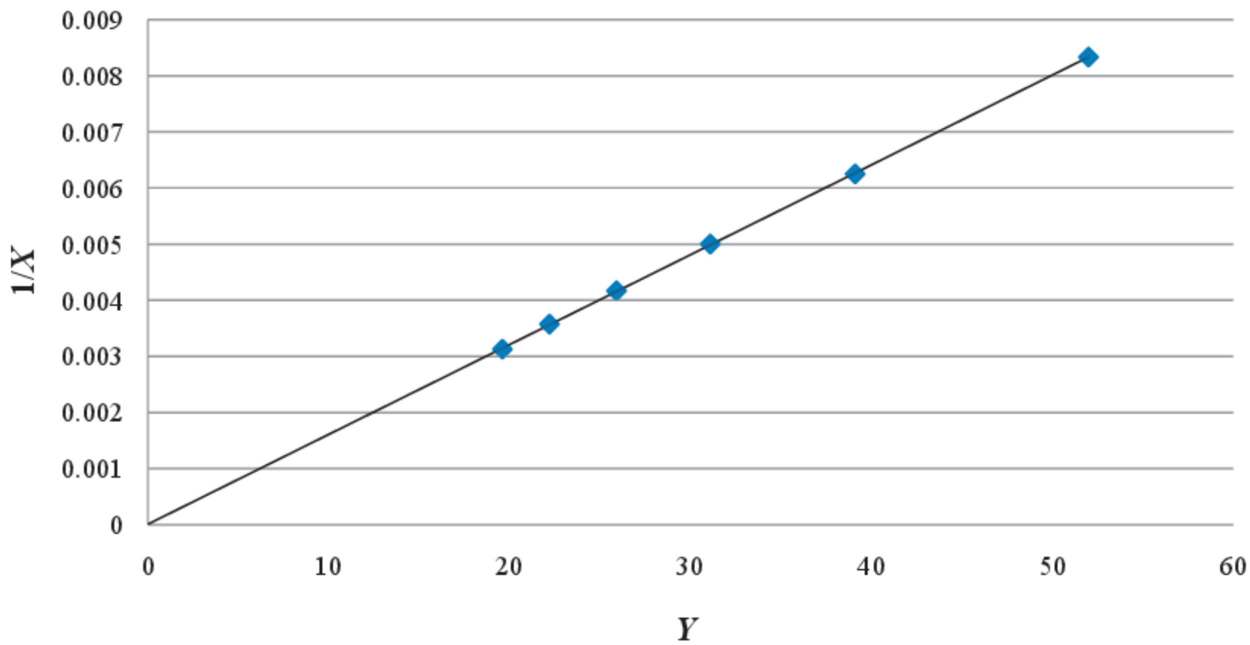
X	**120**	**160**	**200**	**240**	**280**	**320**
1/X	0.0083	0.00625	0.005	0.0042	0.0036	0.0031
Y	**52**	**39.1**	**31.1**	**25.9**	**22.2**	**19.6**
1/Y	0.019	0.026	0.032	0.039	0.045	0.051

Explain how your graph verifies Boyle's law.
straight line through the origin implies p inversely proportional to V / $p \propto \frac{1}{V}$ / pV constant 3

Question 2: *X* vs 1/*Y*



Question 2: *Y* vs 1/*X*



Question 4

6. (i) State Newton's law of universal gravitation.

force proportional to product of masses // $F \propto \frac{m_1 m_2}{d^2}$ / $F = \frac{G m_1 m_2}{d^2}$ 3

inversely proportional to square of distance // correct notation given 3

(ii) Explain what is meant by angular velocity. Derive an equation for the angular velocity of an object in terms of its linear velocity when the object moves in a circle.

rate of change of angle // $\frac{\theta}{t}$ and correct notation given 3

$\omega = \frac{\theta}{t}$ *(stated or implied)* 3

$\omega = \frac{vt}{rt}$ / $\frac{v}{r}$ 3

The International Space Station (ISS), shown in the photograph, functions as a research laboratory and a location for testing of equipment required for trips to the moon and to Mars. The ISS orbits the earth at an altitude of 4.13 × 10^5 m every 92 minutes 50 seconds.

(iii) Calculate (*a*) the angular velocity, (*b*) the linear velocity, of the ISS.

$\omega = \frac{2\pi}{T}$ 3

$\omega = \frac{2\pi}{5570}$ /1.1×10^{-3} s^{-1} *(−1 for omission of or incorrect units)* 3

$v = r\omega$ 3

$v = (6.783 \times 10^6) \times (1.1 \times 10^{-3}) = 7651.5$ m s^{-1} 3

(−1 for omission of or incorrect units)

(iv) Name the type of acceleration that the ISS experiences as it travels in a circular orbit around the earth.

centripetal / gravitational 3

What force provides this acceleration?

gravitational *(do not accept "gravity")* 3

(v) Calculate the attractive force between the earth and the ISS.

$F = \frac{mv^2}{r}$ // $F = mr\omega^2$ 3

$F = 3.884 \times 10^6$ N *(−1 for omission of or incorrect units)* 3

Hence or otherwise, calculate the mass of the earth.

$F = \frac{GmM}{r^2}$ // $T^2 = \frac{4\pi^2 r^3}{GM}$ // $g = \frac{GM}{r^2}$ 3

$M = \frac{Fr^2}{Gm}$ // $M = \frac{4\pi^2 r^3}{GT^2}$ // $M = \frac{(8.63)r^2}{G}$ 3

$M = 5.95 \times 10^{24}$ kg *(−1 for omission of or incorrect units)* 3

(vi) If the value of the acceleration due to gravity on the ISS is 8.63 m s^{-2}, why do occupants of the ISS experience apparent weightlessness?

they are in freefall // ISS accelerating at the same rate as occupants 3

(vii) A geostationary communications satellite orbits the earth at a much higher altitude than the ISS. What is the period of a geostationary communications satellite?

1 day 5

(mass of ISS = 4.5 × 10^5 kg; radius of the earth = 6.37 × 10^6 m)

Question 5

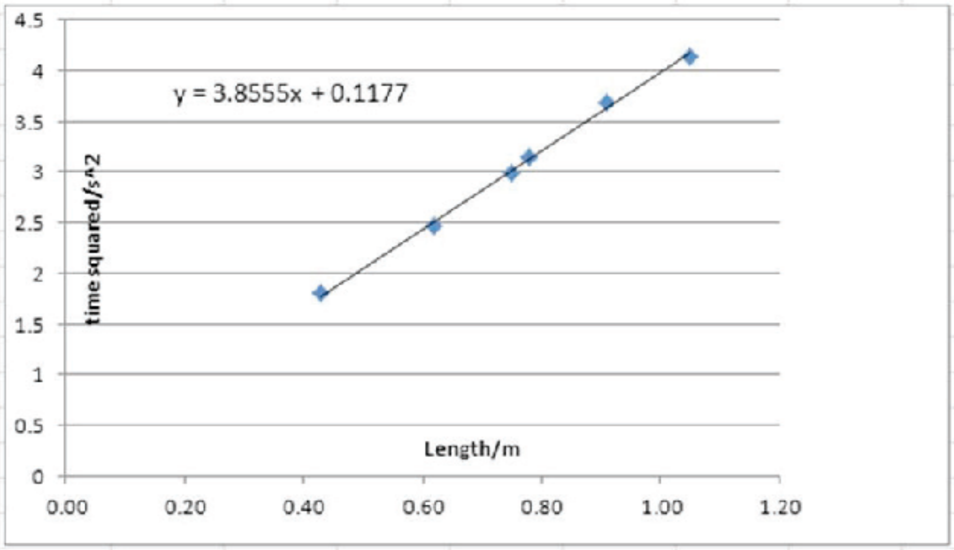
Describe how the student obtained a value for the length of the pendulum and its corresponding periodic time.

measure length (l) from fixed point to top of bob (using metre stick) 3
measure diameter/radius (r) of bob 3
length $= l + r$ (stated or implied) 3
reference to metre rule and Vernier calipers (or micrometer) 3

measure time for n oscillations 3
divide (total time) by n 3

Draw the appropriate graph on this examination paper and use it to calculate a value for g.

L/m	T^2/s^2
0.43	1.8
0.62	2.46
0.75	2.98
0.78	3.15
0.91	3.68
1.05	4.14



correct method for slope **(–1 if (0,0) chosen as point on graph)** 3
correct slope value ($3.47 \leq m \leq 4.14$ s^2 m^{-1}) 6

$g = 4\pi^2 \frac{l}{T^2}$ state/imply 3
value for g ($9.5 \leq g \leq 11.0$ m s^{-2}) **(–1 for omission of or incorrect units)** 3

Give two factors that affect the accuracy of the measurement of the periodic time.
Number of oscillations selected / the precision of the timer / repetition (of measurement for average) / smaller % error in T with longer lengths / nature of the string e.g. 'inextensible string'

any *two* factors 4+3

Question 6

Draw a labelled diagram of the apparatus used in the experiment.

gas container, pressure gauge, scale for reading volume, means of adjusting p or V, e.g. pump/valve

(–1 if no label) 3 marks per component — 4×3

How was the pressure of the gas varied during the experiment?

pump // rotate wheel/screw // move piston/plunger // adjust liquid level in reservoir tube //open valve — 3

Describe how the pressure and the volume of the gas were measured.

(pressure) from the (Bourdon) gauge/pc screen : (volume) from the scale on the gas container/syringe — 2×2

Why should there be a delay between adjusting the pressure of the gas and recording its value?

allow for gas to cool /to reach thermal equilibrium // allow oil (level) to settle — 3

Draw a suitable graph to show the relationship between the pressure and the volume of a fixed mass of gas. Explain how your graph verifies Boyle's law.

label axes correctly on graph paper — 3

plot six points correctly **(–1 per each incorrect point; –1 mark if inappropriate scale)** — 3

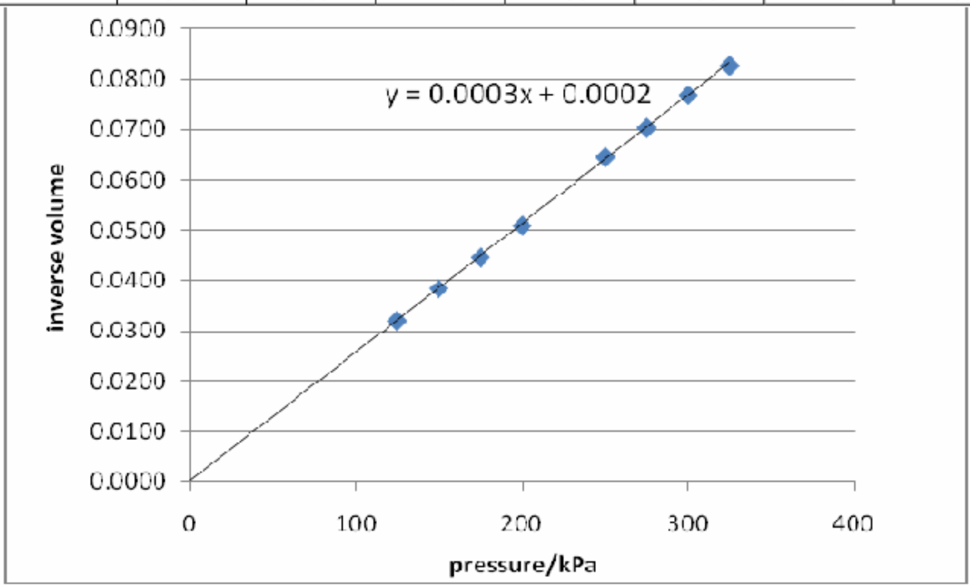
straight line — 3

good distribution — 3

straight line through the origin — 3

$p \propto \frac{1}{V}$ // pV = constant — 3

V/ cm^3	12.1	13.0	14.2	15.5	19.6	22.4	26.0	31.1
1 / V	**0.0826**	**0.0769**	**0.0704**	**0.0645**	**0.0510**	**0.0446**	**0.0385**	**0.0322**
P	**325**	**300**	**275**	**250**	**200**	**175**	**150**	**125**



Question 7

(*a*) **State the law of flotation.**

(when a body floats,) its weight equals — 4

the weight of fluid/liquid/water displaced **(–1 if 'weight' term not used)** — 3

Question 8

(*b*) **The head of a thumbtack has an area of 500 mm^2. Its point has an area of 0.3 mm^2. The pressure exerted at the head of the thumbtack is 12 Pa. What is the pressure exerted at the point of the thumbtack?**

(at head:) $F = P \times A$ / $F = 12(500 \times 10^{-6})$ / $F = 6.0 \times 10^{-3}$ (N) — 4

(at point:) $P = \frac{12\,(500 \times 10^{-6})}{(0.3 \times 10^{-6})}$ / 2.0×10^{4} Pa **(no penalty for units)** — 3

Question 9

Question 6

State Newton's law of universal gravitation.

force proportional to product of masses // correct relationship for F, masses and d 3

inversely proportional to square of distance // correct notation **(-1 for each one omitted)** 3

The international space station (ISS) moves in a circular orbit around the equator at a height of 400 km.

What type of force is required to keep the ISS in orbit?

centripetal (force) / gravitational (force) 3

What is the direction of this force?

towards the centre (of the orbit) / inwards / towards the earth 3

Calculate the acceleration due to gravity at a point 400 km above the surface of the earth.

$GM = gR^2$ // $g \propto \frac{1}{R^2}$ 5

3

$g_1 = \frac{GM}{R^2}$ // $\frac{g_1}{g} = \frac{R^2}{R_1^2}$

$g_1 = 8.564 \approx 8.6 \text{ m s}^{-2}$ // $g_1 = 8.6898 \approx 8.7 \text{ m s}^{-2}$ **(not awarded if h omitted)** 3

(–1 for omission of or incorrect units)

An astronaut in the ISS appears weightless. Explain why.

any correct relevant answer, e.g. he/she is in a state of free-fall; there is no contact force; force of gravity is the only force acting; force of gravity cannot be felt; etc. 3

Derive the relationship between the period of the ISS, the radius of its orbit and the mass of the earth.

$\frac{GMm}{R^2} = \frac{mv^2}{R}$	$T = \frac{2\pi}{\omega}$	$T = \frac{2\pi R}{v}$	3
$GM = v^2 R$	$T^2 = \frac{4\pi^2}{\omega^2}$	$T^2 = \frac{4\pi^2 R^2}{v^2}$	3
$T = \frac{2\pi R}{v}$	$\omega^2 R^3 = GM$	$v^2 R = GM$	3
$T^2 = \frac{4\pi^2 R^3}{GM}$	$T^2 = \frac{4\pi^2 R^3}{GM}$	$T^2 = \frac{4\pi^2 R^3}{GM}$	3

Calculate the period of an orbit of the ISS.

$T^2 = \frac{4\pi^2 (6.8\times10^6)^3}{(6.6\times10^{-11})(6.0\times10^{24})}$ / 3.1347×10^7 **(not awarded if h omitted)** 3

$T = 5.599\times10^3$ s / 93.31 min / 1.56 h **(–1 for omission of or incorrect units)** 3

After an orbit, the ISS will be above a different point on the earth's surface. Explain why.

ISS has a different period to that of the earth's rotation / not in geostationary orbit /etc. any one 6

How many times does an astronaut on the ISS see the sun rise in a 24 hour period?

(24 ÷ 1.56 + 1) / 16 (sunrises) / 15 (sunrises) 6

(gravitational constant = 6.6×10^{-11} N m^2 kg^{-2};
mass of the earth = 6.0×10^{24} kg; radius of the earth = 6.4×10^6 m)

Question 10

Question 1

A student investigated the laws of equilibrium for a set of co-planar forces acting on a metre stick. The student found that the centre of gravity of the metre stick was at the 50.4 cm mark and its weight was 1.2 N.

How did the student find:

(i) **the centre of gravity,**
metre stick on a pivot (e.g. wedge, thread support, bench edge, etc.) / correct diagram 6

(ii) **the weight, of the metre stick?**
place on a newton balance / weighing scales (-1 if no reference to weight / N / g) 6

Why is the centre of gravity of the metre stick not at the 50.0 cm mark?
non-uniform / chipped / worn, etc. // zero mark / 100 cm not (exactly) at one end 3

The student applied vertical forces to the metre stick and adjusted them until the metre stick was in equilibrium.
How did the student know that the metre stick was in equilibrium?
(metre stick was) at rest / stationary / balanced / horizontal / level // "the forces and the moments both balance" 4

The student recorded the following data.

position on metre stick / cm	11.5	26.2	38.3	70.4	80.2
magnitude of force / N	2.0	4.5	3.0	5.7	4.0
direction of force	down	up	down	up	down

Calculate:

(i) **the net force acting on the metre stick**
F_{up} = 4.5 + 5.7 = 10.2 and F_{down} = 2 + 3 +1.2 +4 = 10.2 N / net force = 0 3

(ii) **the total clockwise moment about a vertical axis of the metre stick**
(For any axis e.g. through zero:)
C.T.M. = 2(0.115) + 3(0.383) +1.2(0.504) +4.0(0.802)
or 0.23+1.149+0.6048+3.208 or 5.1918 N m or 5.2 N m 6

(iii) **the total anti-clockwise moment about a vertical axis of the metre stick.**
(for same axis), A.C.T.M. = 4.5(0.262) +5.7(0.704) or 5.1918 N m or 5.2 N m 6
(For (ii) and (iii), penalise once only: -1 for omission of or incorrect units)

[State/imply: turning moment = force x (perp) distance …. award 6 marks if zero credit gained for (ii) and (iii) above]

Use these results to verify the laws of equilibrium.
net force is zero / F_{up} = F_{down} // net turning moment is zero / C.(T.) M = A.C.(T.).M
any one law 6
(final 6 marks awarded only for verification of laws arising from preceding calculations)

Question 11

(a) **State Archimedes' principle.**
upthrust / buoyancy / (apparent) loss in weight (in fluid) equals 4
weight of fluid/ liquid/water displaced 3

Question 12

(b) **Why is it easier to turn a nut using a longer spanner than a shorter one? (7)**

greater <u>torque</u> / <u>(turning) moment</u> /turning effect 7
'distance from effort to fulcrum is greater' (4)

Question 13

(a) **Define pressure. (6)**

force // F/A 3
per unit area // explain notation 3

Is pressure a vector quantity or a scalar quantity? Justify your answer. (6)

scalar 3
it acts in all directions / it has no direction 3

State Boyle's law. (6)

$P \;\alpha\; 1/V$ // PV = constant 3
for a fixed mass of gas at constant temperature 3

A small bubble of gas rises from the bottom of a lake. The volume of the bubble increases threefold when it reaches the surface of the lake where the atmospheric pressure is 1.01×10^5 Pa. The temperature of the lake is 4 °C.
Calculate

(i) the pressure at the bottom of the lake;
(ii) the depth of the lake. (10)

(acceleration due to gravity = 9.8 m s^{-2}; density of water = 1.0×10^3 kg m^{-3})

pressure at bottom (= 3 times pressure at top) = 3.03×10^5 Pa 3

pressure at bottom <u>due to water</u> = 2.02×10^5 Pa 3
$P = h\rho g$ 2
h (= $P/\rho g$) = $2.02 \times 10^5 / [(1.0 \times 10^3)(9.8)]$ / 20.6(1) m 2
(-1 for omission of or incorrect unit)

Question 14

(a) A container contains 5.0 kg of water. If the area of the base of the container is 0.5 m^2 calculate the pressure at the base of the container due to the water. (7) (g = 9.8 m s^{-2})

$P = F/A$ = [(5.0)(9.8)/(0.5)] 4

P = 98 Pa **(-1 for omission of or incorrect unit)** 3

Question 15

(b) State Boyle's law. (7)

pressure is inversely proportional to volume / $p \,\alpha\, 1/V$ / $pV = k$ 4

for a definite mass of gas at constant temperature 3

Question 16

***(a)* State Boyle's law.**

pressure is inversely proportional to volume // $P \;\alpha\; \frac{1}{V}$ // PV = constant (= k) 4

fixed mass of gas at constant temperature 3