Question 1

a.

i) Initial volume 1000 mm^3; final volume 1000.40 mm^3 ☑ Increased (trivial)

ii) Bonds between atoms stretched, so a net volume increase reasonable **owtte** ☑

iii) lateral strain= (-)0.0003; longitudinal strain= 0.001. So Poisson Ratio (-)0.3 ☑.

b.

i) Use binomial theorem or error theory ideas :

$V = lA$ so $\frac{\delta V}{V} = \frac{\delta A}{A} + \frac{\delta l}{l}$, from binomial or by differentiation.

Since $\frac{\delta V}{V} = 0$ for rubber, and since $\frac{\delta l}{l}$ increases by 2%, then $\frac{\delta A}{A}$ reduces by 2% ☑

ii) $A = w^2$ so $\frac{\delta A}{A} = 2\frac{\delta w}{w}$. Hence $\frac{\delta w}{w}$ is reduced by 1% ☑

iii) By inspection (-)0.5 ☑

[6 marks]

Question 2

a) i) $\sigma = 0.5$ ☑ $mg / \pi r^2$ ☑ $= 0.5 \times 70 \times 10 / \pi (0.015)^2 = 495$ kPa ☑

(486 kPa with g = 9.8)

ii) Stress doubles ☑; then increases considerably due to impact of running strides. ☑

b) i) As volume scales as the cube of scale factor, 1 000 000 times as big. ☑

ii) Cross sectional areas scale by 10, 000 ☑, so only 100 times the stress, ☑

iii) A Brobingnagian on one foot is dangerously close to the failure stress for his thigh bone: thinner bones in the lower leg would therefore break. ☑ His walk would be likely to be a shuffle maintaining support from both legs, while running would be impossible. ☑ owtte (Not so much so for small Brobdingnagian children!)

c) The converse of the above argument is that small scale models will easily be strong enough to stand up while their full scale counterparts may not ☑. So the model may well be useful to determine whether the geometry works, but to test strength, cross-sections would need to be adjusted to allow for the way in which stresses scale. ☑ Any sensible extension scores.

Total 12 ☑

Question 3

(a) $[E] =$ kg m s^{-2} m^{-2} = kg m^{-1} s^{-2} ✓

$[\rho] =$ kg m^{-3} ✓

$[g] =$ m s^{-2} ✓

[3]

(b) Units m = kg m^{-1} s^{-2} x (kg m^{-3})$^{\alpha}$ x (m s^{-2})$^{\beta}$ ✓

m = m^{-1} x m$^{-3\alpha}$ x m$^{\beta}$ $\beta = 2 + 3\alpha$

(kg)^0 = kg x (kg)$^{\alpha}$ $\alpha = -1$

s^0 = s^{-2} x s$^{-2\beta}$ $\beta = -1$

only two equations needed to solve for α and β

one mark each for a correct equation ✓✓

$h = \text{constant} \times \dfrac{E}{\rho g}$ ✓

(α and β are not specifically required – correct result will suffice)

[4]

(c) $h = 1 \times \dfrac{10^{10}}{3 \times 10^3 \times 10}$ ✓

= 3.3 x 10^5 metres ≈ 300 km ✓

[2]

[Q5: 9 marks]

Question 4

(a) $Stress = \dfrac{Force}{Area} = \dfrac{0.5 \times 70 \times 9.81}{5.0 \times 10^{-4}}$ ✓

= 7 x 10^5 Nm^{-2} ✓

(b) *ratio = 0.07* ecf ✓

(c) *mass of giant* = 9^3 ✓ x 70 (✓)

= 5.1 x 10^4 kg ✓

(d) $stress = \dfrac{0.5 \times 5.1 \times 10^4 \times 9.81}{9^2 \times 5.0 \times 10^4}$ ecf

= 6.2 x 10^6 Nm^{-2} ✓

ratio = 0.6 ecf ✓

(e) The ratio will be 1.2 and he will break his leg. owtte ✓

[8]

Question 5

a) (i) 6 ✓

(ii) a^2 } these two steps ✓

(iii) F/a^2

(iv) x/a ✓

(v) $E = \sigma/\varepsilon = (F/a^2)/(x/a) = F/xa$ ✓

so $E = k/a$ ✓

(5)

b)

(i) 6 } both answers ✓

(ii) 3

(iii) 12 ✓

(this arrangement would be *hexagonal close packed* and, whilst *fcc* would also have a coord no. of 6, *bcc* would be 8)

(iv) all bonds intact, so no relative movement of atoms / still solid ✓

smaller k ('weaker') means lower E **or** elastically softer material ✓

Reference to expansion is due to the anharmonic nature of the bond, i.e. the force to compress and the force to expand are slightly different. For this a non-ideal spring is needed. Allow a mark if reference to the microscopic and macroscopic behaviour together.

(v) Specific latent heats for some simple elements:

Element	**SLH (Fusion)** /kJ kg^{-1}	**SLH (Vaporisation)** /kJ kg^{-1}	F : (F + V) no units ✓
argon	29.5	161	0.155
helium	3.45	20.7	0.143
hydrogen (H_2)	59.5	445	0.118
krypton	16.3	108	0.131
neon	16.8	84.8	0.165
			0.142 average ✓

So 14% or approximately one in seven bonds are broken on fusion and the remainder on vaporisation ✓

Bonus mark realise that H_2 is the odd-one-out; average now 0.15 (✓)

(8)

[13 marks]

Question 6

Question			Answer	Marks	Guidance
	(a)		The extension of each spring is halved because the force in each spring is halved. (Hence the force constant is *2k*.)	B1	**Allow** F = kx, x is halved for the same F, hence k doubles.
	(b)	(i)	Missing data point and error bar plotted correctly.	B1	**Allow** ½ square tolerance.
		(ii)	Force measured by pulling back plate with a newton-meter. Extension measured with a ruler (placed close to the transparent plastic tube).	B1 B1	
		(iii)	Best fit line drawn correctly and gradient determined correctly. Worst fit line drawn correctly and its gradient determined correctly. $2k$ = 50 (N m^{-1}), therefore k = 25 (N m^{-1}) Absolute uncertainty determined correctly.	B1 B1 B1 B1	**Ignore** POT for this mark; gradient = 50 ± 4 (N m^{-1}) **Note**: The line must have a greater/smaller gradient than the best fit line and must pass through all the error bars. **Ignore** POT for this mark. Possible ECF. Possible ECF within calculation.
		(iv)	$F \propto x$ / straight line passing through the <u>origin</u>.	B1	
		(v)	energy stored = ½ × 50 × 0.12^2 ½ × 50 × 0.12^2 = ½ × 0.39 × v^2 v = 1.4 (m s^{-1})	C1 C1 A1	Possible ECF from **(iii)** **Allow** 1 mark for v = 0.96 m s^{-1}; used k for single spring

Question			Answer	Marks	Guidance
	(c)		force constant of spring arrangement) = $\frac{2k}{3}$ $\frac{2k}{3}x = ma$ $a = \frac{2}{3 \times 0.39}kx$ $a = 1.7\ kx$	M1 M1 A0	
			Total	**14**	

<table>
<tr><th>Q</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>7 (a)</td><td>GPE lost = KE gained
$mgh = ½ mv^2$
$v^2 = 2gh$
Speed of 1 kg mass at collision = $\sqrt{2gh} = 2\sqrt{9.81}$ m s^{-1}
Speed of platform and ball after collision using conservation of momentum
$mv = 3mV$ (V = speed after collision)
$V = \frac{v}{3} = \frac{2\sqrt{9.81}}{3}$
KE after $= \frac{1}{2}mV^2 = \frac{1}{2}\frac{3\times4\times9.81}{9} = \frac{2}{3}g$ J
Total initial energy was $mgh = 1 \times 2 \times 9.81 = 2g$ J
Missing energy = Heat radiated = $2g - (\frac{2}{3})g = \frac{4}{3}$ g =13.1 J</td><td rowspan="4">Thorough understanding of these applications of physics.

OR

Partially correct mathematical solution to the given problems.

AND / OR

Partial understanding of these applications of physics.</td><td rowspan="4">(Partially) correct mathematical solution to the given problems.

AND / OR

Reasonably thorough understanding of these applications of physics.</td><td rowspan="4">Correct mathematical solution to the given problems.

AND

Thorough understanding of these applications of physics</td></tr>
<tr><td>(b)</td><td>x = initial compression due to platform
$= \frac{mg}{k} = \frac{2\times9.81}{100} = 0.1962$ m
y = extra compression due to addition of the falling 1kg mass.
KE + Initial EPE + loss of GPE = Final EPE
$½ mv^2 + ½kx^2 + mgy = ½k(x + y)^2$
$\frac{1}{2}\times3\times\left(\frac{2\sqrt{9.81}}{3}\right)^2 + \frac{1}{2}\times100\times0.1962^2 + 3\times9.81y$
$= 50(0.1962^2 + 0.3924y + y^2)$
$6.54 + 1.924722 + 29.43y = 1.924722 + 19.62y + 50y^2$
$50y^2 - 9.81y - 6.54 = 0$
$y = \frac{9.81\pm\sqrt{9.81^2 - (4\times50\times-6.54)}}{2\times50}$
$= \frac{9.81\pm\sqrt{1404.236}}{100} = \frac{47.28}{100}$ (ignore negative root)
Extra compression = y = 0.4728 m</td></tr>
<tr><td>(c)</td><td>New equilibrium point is compression of 29.43 cm.
Max displacement from unstretched length = 66.90 cm
Amplitude to 37.47 cm</td></tr>
<tr><td>(d)</td><td>By comparing the total energy at the bottom of the motion with the total energy at the top of the motion.
Energy stored at base = $½k(x + y)^2$
$= 0.5 \times 100 \times (0.4728 + 0.1962)^2 = 22.378$ J
Energy stored at top = $mg\Delta h + ½$ k 0.0804^2
$= 3 \times 9.81 \times (2 \times 0.3747) + 0.5 \times 100 \times 0.0804^2$
$= 22.0548 + 0.3232 = 22.378$ J</td></tr>
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