Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Spot the mistakes

ANSWER U · 4

i. A swing from one side to the other is only half an oscillation, so 20 such swings are 10 oscillations: $T = 19.8 \div 10 = 1.98$ s. And the effective length runs to the center of the bob: $l = 95.0 + 4.0 \div 2 = 97.0$ cm $= 0.970$ m.

ii. $g = 4\pi^2 l/T^2 = 39.44 \times 0.970 \div 1.98^2 = 38.26 \div 3.92 =$ **$9.76\ m/s^2$**, close to the true value.

MARKING SCHEME

- ✓ 20 swings one way are only 10 oscillations, so $T = 1.98$ s.
- ✓ The effective length includes the bob's radius: $l = 0.970$ m.
- ✓ $g = 39.44 \times 0.970 \div 1.98^2$ written.
- ✓ $g = 9.76\ m/s^2$.

2 A clock on a hot day

ANSWER A · 3

$T \propto \sqrt{l}$, so the new period is $T \times \sqrt{1.0010} = T \times 1.0005$: each swing takes 0.05% longer.
The clock counts too few swings by about the same fraction, so in a day it loses $86{,}400 \times 0.0005 \approx$ **43 s**.

MARKING SCHEME

- ✓ $T \propto \sqrt{l}$, so T grows by the factor $\sqrt{1.0010} \approx 1.0005$ (half the percentage).
- ✓ The clock runs slow by 0.05%.
- ✓ $86{,}400 \times 0.0005 \approx 43$ s a day.

3 Which reading is wrong?

ANSWER HA · 5

i. $T = 1.27, 1.72, 1.795, 2.005$ s; $T^2 = 1.61, 2.96, 3.22, 4.02\ s^2$.

ii. The reading at **$l = 0.60$ m**. T^2 should be proportional to l, so T^2/l should be the same each time: it is 4.03, 4.93, 4.03 and $4.02\ s^2/m$.

iii. Slope $= (4.02 - 1.61) \div (1.00 - 0.40) = 4.0\ s^2/m$, so $g = 4\pi^2 \div$ slope $= 39.44 \div 4.01 \approx$ **$9.8\ m/s^2$**.

iv. $T^2 = 4.02 \times 0.60 = 2.41\ s^2$, $T = 1.55$ s, so 20 oscillations take about **31 s**.

MARKING SCHEME

- ✓ The T and T^2 rows correct.
- ✓ The 0.60 m reading picked out.
- ✓ The reason: T^2/l (or the straight line through the origin) fits the other three but not this one.
- ✓ Slope $\approx 4.0\ s^2/m$, so $g \approx 9.8\ m/s^2$.
- ✓ The time should have been about 31 s.

4 Half the grip

ANSWER A · 4

i. $v = \sqrt{(Fr/m)}$. Dry: $\sqrt{(60{,}000 \times 50 \div 12{,}000)} = \sqrt{250} = 15.8$ m/s = **57 km/h**. Wet: $\sqrt{(30{,}000 \times 50 \div 12{,}000)} = \sqrt{125} = 11.2$ m/s = **40 km/h**.

ii. More than he needs. $F \propto v^2$, so half the force allows a speed of $1 \div \sqrt{2} \approx 0.71$ of the earlier speed, not 0.5. Half the speed would need only a quarter of the force. Milan's rule is safe, but it slows the bus to 28 km/h, when 40 km/h would do.

MARKING SCHEME

- ✓ $v = \sqrt{(Fr/m)}$, from $mv^2/r = F$.
- ✓ Dry 15.8 m/s = 57 km/h.
- ✓ Wet 11.2 m/s = 40 km/h.
- ✓ $F \propto v^2$, so the speed falls only by the factor $\sqrt{2}$, and halving it is more than needed.

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5 Is the ride possible?

ANSWER A · 4

i. $v^2/r = g$, so $v = \sqrt{(gr)} = \sqrt{(9.8 \times 10)} = 9.9$ m/s. $T = 2\pi r/v = 2 \times 3.14 \times 10 \div 9.9 =$ **6.3 s** a round.

ii. $v = 2\pi r/T = 62.8 \div 40 = 1.57$ m/s, and $a = v^2/r = 1.57^2 \div 10 =$ **0.25 m/s²**, about a fortieth of g (0.25 ÷ 9.8 = 0.025). So the rider hardly feels lighter at the top.

MARKING SCHEME

- ✓ $v = \sqrt{(gr)} = 9.9$ m/s.
- ✓ $T = 2\pi r/v = 6.3$ s.
- ✓ At T = 40 s, v = 1.57 m/s.
- ✓ $a = 0.25$ m/s², about a fortieth of g.

6 Find a height from a day

ANSWER HA · 5

i. $v^2/r = GM/r^2$. With $v = 2\pi r/T$: $4\pi^2 r/T^2 = GM/r^2$, so $r^3 = GMT^2/(4\pi^2)$.

ii. T = 86,400 s, so $r^3 = 3.98 \times 10^{14} \times (86{,}400)^2 \div 39.44 = 7.53 \times 10^{22}$ m³, and $r =$ **4.22×10^7 m**, about 42,200 km from the center. The height is 42,200 − 6,371 ≈ **35,900 km**. (The unit's table gives 35,786 km; the small difference comes from using a rounded 24-hour period and 3.14.)

iii. It doesn't matter: m is on both sides of the first equation and cancels.

MARKING SCHEME

- ✓ $4\pi^2 r/T^2 = GM/r^2$ by putting in $v = 2\pi r/T$.
- ✓ $r^3 = GMT^2/(4\pi^2)$.
- ✓ $r \approx 4.22 \times 10^7$ m.
- ✓ Height ≈ 35,900 km.
- ✓ m cancels, so the mass doesn't matter.

7 Too fast and too slow

ANSWER HA · 5

i. Energy per kilogram: $\frac{1}{2}v^2 = \frac{1}{2}v_e^2 + \frac{1}{2}v\infty^2$, with $v_e = 11.2$ km/s. So $v\infty = \sqrt{(15^2 - 11.2^2)} = \sqrt{99.6} =$ **10 km/s**.

ii. Kinetic energy per kilogram: $\frac{1}{2} \times 5000^2 = 1.25 \times 10^7$ J/kg. At the top, $V = -6.25 \times 10^7 + 1.25 \times 10^7 = -5.0 \times 10^7$ J/kg. From $V = -GM/r$: $r = 3.98 \times 10^{14} \div (5.0 \times 10^7) = 7.96 \times 10^6$ m = 7,960 km. Height = 7,960 − 6,371 = **1,589 km** (about 1,590 km).

iii. mgh takes g as 9.8 m/s² all the way, but g gets weaker as the probe rises, so it is slowed less than she has allowed for, and it goes higher.

MARKING SCHEME

- ✓ $\frac{1}{2}v^2 = \frac{1}{2}v_e^2 + \frac{1}{2}v\infty^2$, or the kinetic energy left after paying 6.25×10^7 J/kg.
- ✓ $v\infty \approx 10$ km/s.
- ✓ V at the top $= -5.0 \times 10^7$ J/kg.
- ✓ r = 7,960 km, height ≈ 1,590 km.
- ✓ g falls with height, so mgh takes too much energy for each meter risen and gives too small a height.

8 Predict, then explain

MARKING SCHEME U · 3

- ✓ E is twice as big, from M/R^2.
- ✓ The escape velocity is the same, from M/R.
- ✓ The period is shorter, since g is bigger.

9 Pass or fail?

ANSWER

i. $h = (10{,}000 \times 1.2 + 1{,}500 \times 3.0) \div (10{,}000 + 1{,}500) = 16{,}500 \div 11{,}500 =$ **1.43 m**.

ii. $\tan\theta = (b/2)/h = 1.0 \div 1.435 = 0.697$, so $\theta \approx$ **34.9°**: it just fails.

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iii. To pass, $\tan\theta \geq 0.70$, so $h \leq 1.0 \div 0.70 = 1.43$ m (1.429). With a load x: $(12{,}000 + 3x) \div (10{,}000 + x) = 1.429$, so $12{,}000 + 3x = 14{,}290 + 1.429x$, $1.571x = 2{,}290$, and $x \approx$ **1,460 kg**. (This is a made-up bus: the unit's example shows that a real one tips sooner, because of its springs.) HA · 5

MARKING SCHEME

- ✓ Moments give $h = 16{,}500 \div 11{,}500 = 1.43$ m.
- ✓ $\tan\theta = 1.0 \div 1.43$, $\theta \approx 34.9°$.
- ✓ It just fails.
- ✓ The limit is $h = 1.0 \div 0.70 = 1.43$ m, with the equation for x.
- ✓ $x \approx 1{,}460$ kg (accept about 1,450 kg, by rounding).

10 Work backwards

ANSWER A · 2

About the knife edge: the 50 g is 30 cm to one side, and the stick's weight, at its 50 cm mark, 10 cm to the other. $m \times 10 = 50 \times 30$, so $m =$ **150 g**.

MARKING SCHEME

- ✓ The stick's weight acts at 50 cm, 10 cm from the knife edge: $m \times 10 = 50 \times 30$.
- ✓ $m = 150$ g.

11 Design a measurement

ANSWER A · 4

i. 1.7% of 2 s is 0.034 s, far below 0.2 s, so one oscillation can't show it. Over 20 oscillations the difference is $20 \times 0.034 = 0.68$ s, more than the 0.2 s error.

ii. She changes the angle (30° and a small angle). She keeps the same length and bob, and the same way of letting go and timing.

iii. The swing dies away, so the angle doesn't stay at 30° for 20 oscillations, and the difference will be less than 1.7%. Using a heavy bob, which loses its swing to the air only slowly, and repeating the timing helps.

MARKING SCHEME

- ✓ 0.034 s for one oscillation is less than the 0.2 s error.
- ✓ 0.68 s over 20 oscillations is more than the error.
- ✓ Changes the angle; keeps the length and the bob (or any two sensible ones).
- ✓ The amplitude shrinks as it swings; a heavy bob, or repeats, helps.

12 Correct the misconceptions

ANSWER U · 3

1. The mud doesn't fly along the radius. Nothing pushes it outwards: it goes straight on along the tangent at the point where it leaves.
2. The centrifugal force is not the reaction to the centripetal force. It is a pseudo force, felt only from inside the turning body; the reaction to a pull on a body acts on whatever is doing the pulling.
3. Points of a wheel turn once in the same time, but points farther out go round a bigger circle, so they move faster ($v = 2\pi r/T$).

MARKING SCHEME

- ✓ The mud flies along the tangent, not along the radius.
- ✓ The centrifugal force is a pseudo force, not the reaction to the centripetal force.
- ✓ Points farther from the center move faster, since $v = 2\pi r/T$ with the same T.

13 Think

ANSWER

No. The fields cancel because they are vectors pointing opposite ways. Potential is a scalar with no direction, and both potentials are negative, so they add:

$V = -3.98 \times 10^{14} \div (3.46 \times 10^{8}) - 4.90 \times 10^{12} \div (3.84 \times 10^{7}) = -1.15 \times 10^{6} - 1.28 \times 10^{5} =$ **-1.28×10^{6}**

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J/kg. HA · 3

It is not zero: the rocket has not reached infinity, and it hasn't escaped.

MARKING SCHEME

✓ Fields are vectors that can cancel; potentials are scalars, both negative, and they add.

✓ $V \approx -1.28 \times 10^6$ J/kg.

✓ So the potential isn't zero, and the rocket hasn't escaped.

14 Make your own

ANSWER HA · 2

$g = 4\pi^2 l/T^2 = 39.44 \times 1.0 \div 16 =$ **2.47 m/s²**. For example, with the Earth's radius, 6.371×10^6 m: $M = gR^2/G = 2.47 \times (6.371 \times 10^6)^2 \div (6.67 \times 10^{-11}) =$ **1.5×10^{24} kg**. Any R works, with $M = gR^2/G$.

MARKING SCHEME

✓ $g = 2.47$ m/s².

✓ $M = gR^2/G$ worked out correctly for the chosen R.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **The Clay Owl** (exhibit): Count the owl's swings in 10 seconds, pushed gently and then harder: the time period depends on the string's length, not on the amplitude.
- **The Chime Instrument** (exhibit): Strike a bar: it vibrates to and fro about its rest position, an oscillatory motion, and a shorter bar vibrates with a higher frequency.
- **Sand Lissajous Pendulum** (exhibit): Swing the pendulum two ways at once: each swing repeats in equal times, and their frequency ratio sets the curve drawn in the sand.
- **Chaotic Pendulum** (exhibit): This double pendulum swings without ever quite repeating itself: unlike a single pendulum, its motion is not periodic.
- **Water Parabola** (exhibit): Spin the base: to move in circles the water needs a push toward the middle, a centripetal force, so its surface rises at the sides.
- **The Balancing Bird** (exhibit): Nudge the bird: its weighted wings put its center of gravity below its beak, so it rocks back to balance, a stable equilibrium.
- **Uphill Cone - Defying Gravity?** (exhibit): Watch the cone's middle, not its ends: its center of gravity sinks lower all the time, even while the cone seems to climb.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	10	17	25	**52**

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