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

1 Spot the error

ANSWER U · 3

60 revolutions per minute is 1 revolution per second, and one revolution is 2π radians, so $\omega = 2\pi \times 1 =$ **6.28 rad/s**, not 60 rad/s.
$v = r\omega = 0.5 \times 6.28 =$ **3.14 m/s**.

MARKING SCHEME

✓ The mistake: rpm is not rad/s.
✓ $\omega = 2\pi f = 2\pi \times 1 = 6.28$ rad/s.
✓ $v = 3.14$ m/s.

2 On a Ferris wheel

ANSWER A · 5

i. $v = 2\pi r/T = 2\pi \times 10 \div 20 =$ **3.14 m/s**; $a = v^2/r = 9.87 \div 10 =$ **0.99 m/s²**.
ii. At the top the resultant force points down: $mg - R = ma$, so $R = 50 \times (9.8 - 0.99) =$ **441 N**. At the bottom it points up: $R - mg = ma$, so $R = 50 \times (9.8 + 0.99) =$ **539 N**. (Her weight is 490 N.)
iii. Weightless at the top when $R = 0$, that is $\omega^2 r = g$: $\omega = \sqrt{(9.8 \div 10)} = 0.99$ rad/s, so $T = 2\pi/\omega =$ **6.3 s**.

MARKING SCHEME

✓ $v = 3.14$ m/s.
✓ $a = 0.99$ m/s².
✓ R at the top $= m(g - a) = 441$ N.
✓ R at the bottom $= m(g + a) = 539$ N.
✓ Weightless at the top when the period is 6.3 s.

3 Design a bend

ANSWER A · 4

i. 36 km/h = 10 m/s. $\tan\theta = v^2/(rg) = 100 \div (40 \times 9.8) = 0.255$, so $\theta =$ **14.3°**.
ii. At 15 m/s it needs a centripetal force $mv^2/r = m \times 5.6$ m/s², but the banked road's normal reaction alone gives only $m \times 2.5$ m/s² towards the center ($mg \tan\theta$). With no friction to make up the difference, the truck **slides up and outward**, off the outside of the bend.

MARKING SCHEME

✓ 36 km/h = 10 m/s and $\tan\theta = v^2/(rg)$.
✓ $\theta = 14.3°$.
✓ At 54 km/h more centripetal force is needed than the banking gives.
✓ With no friction it slides outward (up the bank).

4 Newton's Moon test

ANSWER HA · 4

i. $T = 27.3 \times 86\,400 = 2.36 \times 10^6$ s. $a = 4\pi^2 \times 3.84 \times 10^8 \div (2.36 \times 10^6)^2 =$ **2.72×10^{-3} m/s²**.
ii. $g \div 60^2 = 9.8 \div 3600 =$ **2.72×10^{-3} m/s²**: the same.
iii. The same pull that makes an apple fall, weakened as the square of the distance, is exactly what keeps the Moon in its orbit: gravity reaches out to the Moon and provides its centripetal force.

MARKING SCHEME

✓ T in seconds, 2.36×10^6 s.
✓ $a = 2.72 \times 10^{-3}$ m/s².
✓ $g/60^2 = 2.72 \times 10^{-3}$ m/s², the same.
✓ The Earth's gravity, falling off as $1/d^2$, provides the Moon's centripetal force.

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5 Predict, then explain

ANSWER A · 4

i. The **outer coin** (20 cm). Every coin has the same ω, and the centripetal force it needs is $m\omega^2 r$, largest for the largest r. Friction can give at most μmg, the same for each coin, so the outer one reaches its limit first.

ii. $\mu mg = m\omega^2 r$, so $r = \mu g/\omega^2 = 0.4 \times 9.8 \div 16 =$ **0.245 m** (24.5 cm): all three coins stay.

MARKING SCHEME

✓ The outer coin slides first.

✓ The same ω, so the force needed, $m\omega^2 r$, is largest at the largest r; friction is at most μmg for each.

✓ $\mu mg = m\omega^2 r$.

✓ $r = 0.245$ m.

6 Read the data

ANSWER A · 4

i. v^2: 98, 196, 392 m^2/s^2, doubling as r doubles: $v^2/r = 3.92$ m/s^2 each time. $\mu = v^2/(rg) = 3.92 \div 9.8 =$ **0.4**.

ii. $v = \sqrt{(\mu g r)} = \sqrt{(0.4 \times 9.8 \times 200)} =$ **28 m/s**.

iii. $v \propto \sqrt{r}$, so doubling the radius multiplies the safe speed by $\sqrt{2} \approx 1.41$, not 2 (14.0 → 19.8 m/s).

MARKING SCHEME

✓ v^2/r is the same (3.92 m/s^2) for all three.

✓ $\mu = 0.4$.

✓ 28 m/s at 200 m.

✓ Doubling r multiplies v by $\sqrt{2}$, not 2.

7 Correct the misconceptions

ANSWER U · 3

1. It has an acceleration, v^2/r, towards the center, because the direction of its velocity changes.
2. Seen from the road there is no outward force: friction is the only horizontal force, and it is unbalanced; it is the centripetal force.
3. Without friction the car would go on along the **tangent** (straight on, the way it was moving), not radially outward.

MARKING SCHEME

✓ There is an acceleration towards the center.

✓ No real centrifugal force: friction is unbalanced and provides the centripetal force.

✓ Without friction it moves along the tangent, not outward along the radius.

8 Think

ANSWER HA · 3

No. Gravity pulls the water down with mg all the time. At the top, to go round the circle, the water needs a downward resultant force mv^2/r, which is more than mg when the bucket moves fast. Gravity gives part of it and the bottom of the bucket pushes down for the rest. The water is falling, but the bucket is pulled down and round faster than the water would fall on its own, so the water stays pressed into it.

MARKING SCHEME

✓ Gravity still acts (she is wrong).

✓ At the top the water needs a downward force mv^2/r, more than mg at high speed.

✓ The bucket supplies the rest, pushing on the water, so it stays in.

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9 Make your own

ANSWER HA · 2

The car needs $v^2 \geq gr$ at the top of the loop, which is 2r up. Energy: $mgh = mg(2r) + \frac{1}{2}m(gr)$, so the least $h = 2.5r$. For example $r = 0.2$ m and **$h = 0.5$ m**: at the top $v^2 = 2g(0.5 - 0.4) = 1.96 = g \times 0.2$, exactly gr.

MARKING SCHEME

- ✓ A choice with $h = 2.5r$ (or more).
- ✓ Shown: at the top $v^2 = gr$ from the energy equation.

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.

- **Water Parabola** (exhibit): Spin the base: each bit of water needs a centripetal force, mv^2/r, and the greater pressure of deeper water farther out supplies it.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	17	9	**32**

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