PREPNEST — ANSWER KEY

Physics Unit 3 & 4 — Practice Exam 1 — Answers & Explanations

For a parent, tutor, or the student to mark the exam paper against.

Section A — multiple choice

1. B. the gravitational force of the book on Earth

Newton's third-law pairs act on two different objects and are the same type of force: "Earth pulls the book" pairs with "the book pulls Earth". The normal force of the table on the book balances the book's weight, but that is Newton's first law (both forces act on the book), not a third-law pair — the most common error on this idea.

2. C. 2.04 s

The vertical component is $20.0\sin(30.0°) = 10.0$ m s⁻¹. The time to the top is $\frac{10.0}{9.81} = 1.02$ s and the flight is symmetrical, so the total time is 2.04 s. 1.02 s stops at the highest point; 3.53 s (and half of it, 1.77 s) uses the horizontal component $20.0\cos(30.0°)$.

3. B. 12.9 m s⁻¹

With no friction, the horizontal component of the normal force provides the centripetal force: $\tan(\theta) = \frac{v^2}{rg}$, so $v = \sqrt{rg\tan(12.0°)} = \sqrt{80.0 \times 9.81 \times 0.2126} = 12.9$ m s⁻¹. 28.0 m s⁻¹ leaves out $\tan(\theta)$, 60.8 m s⁻¹ divides by it, and 4.12 m s⁻¹ leaves out g.

4. B. 3.0 J

Momentum is conserved: $2.0 \times 3.0 = 3.0v$, so $v = 2.0$ m s⁻¹. Kinetic energy before is $\frac{1}{2}(2.0)(3.0)^2 = 9.0$ J and after is $\frac{1}{2}(3.0)(2.0)^2 = 6.0$ J, so 3.0 J is transformed (to heat and sound). The collision is inelastic, so 0 J is wrong.

5. B. 6.32 m s⁻¹

The elastic potential energy becomes kinetic energy: $\frac{1}{2}kx^2 = \frac{1}{2}mv^2$, so $v = x\sqrt{\frac{k}{m}} = 0.10\sqrt{4000} = 6.32$ m s⁻¹. 4.47 m s⁻¹ and 8.94 m s⁻¹ drop the $\frac{1}{2}$ from only one side; 20.0 m s⁻¹ uses x instead of x^2.

6. A. 2.45 N kg⁻¹

The altitude equals Earth's radius, so the satellite is $2R_E$ from Earth's centre. $g = \frac{GM_E}{(2R_E)^2}$, a quarter of the surface value: $\frac{9.81}{4} = 2.45$ N kg⁻¹. 4.91 N kg⁻¹ uses the inverse (not inverse-square) law.

7. D. 2.0 m

At P the fields are equal in magnitude: $\frac{kQ}{x^2} = \frac{k(4Q)}{(3.0-x)^2}$, where x is the distance from $+Q$. Then $3.0 - x = 2x$, so $x = 1.0$ m, and P is 2.0 m from the $+4Q$ charge. The null point is closer to the smaller charge. 1.0 m is the distance from $+Q$.

8. D. towards the bottom of the page

For a positive charge moving right in a field into the page, the right-hand rule gives a force towards the top of the page. The electron is negative, so the force is reversed: towards the bottom of the page. The force is always perpendicular to both v and B, so it cannot be into or out of the page.

9. A. Electric field lines begin on positive charges and end on negative charges.

Gravitational forces are only attractive; magnetic poles always come in pairs (no monopoles have been observed); and a magnetic field exerts no force on a stationary charge ($F = qvB$ with $v = 0$).

10. C. 17.0 V

$V_2 = 240 \times \frac{60}{1200} = 12.0$ V RMS, and $V_{\text{peak}} = \sqrt{2} \times 12.0 = 17.0$ V. 12.0 V is the RMS value; 339 V is the primary peak.

11. D. Peak EMF: doubled; Frequency of the output: doubled

Doubling the rotation rate halves the time for each change of flux, so the peak EMF ($\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$) doubles, and the number of cycles each second — the frequency — also doubles.

12. B. 400 W

$I = \frac{P}{V} = \frac{50\,000}{5000} = 10$ A and $P_{\text{loss}} = I^2R = 100 \times 4.0 = 400$ W. 6.25 MW uses $\frac{V^2}{R}$ with the transmission voltage, which is not the voltage across the lines; 40 W is the voltage drop IR mistaken for a power.

13. A. reverses the direction of the current in the coil every half-turn, so the coil keeps turning in the same direction

Without the commutator, the forces on the coil would reverse the rotation each half-turn and the coil would oscillate to rest. Reversing the current every half-turn keeps the torque in the same rotational direction.

14. C. 3.0 mm

$\Delta x = \frac{\lambda L}{d} = \frac{600 \times 10^{-9} \times 2.0}{0.40 \times 10^{-3}} = 3.0 \times 10^{-3}$ m. Converting the slit separation from millimetres is the usual source of error.

15. A. Maximum kinetic energy of photoelectrons: unchanged; Photocurrent: increases

Each photon still has energy hf, so the maximum kinetic energy $hf - \phi$ is unchanged. A more intense beam delivers more photons each second, so more photoelectrons are emitted and the photocurrent increases. The wave model wrongly predicts that the kinetic energy would increase with intensity.

16. C. 1.00×10^{-10} m

$E_k = qV$, so $p = \sqrt{2m_eE_k} = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 150}$ and $\lambda = \frac{h}{p} = 1.00 \times 10^{-10}$ m. 4.01×10^{-20} m uses 150 J instead of 150 eV; 8.28×10^{-9} m treats the electron as a photon ($\lambda = \frac{hc}{E}$).

17. C. 103 nm

$\Delta E = 13.6\left(1 - \frac{1}{9}\right) = 12.09$ eV and $\lambda = \frac{hc}{\Delta E} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{12.09} = 1.03 \times 10^{-7}$ m. 122 nm is the $n = 2 \to 1$ line, 97.4 nm the $n = 4 \to 1$ line and 91.3 nm the ionisation energy (13.6 eV).

18. D. 11 μs

$\gamma = \frac{1}{\sqrt{1 - 0.98^2}} = 5.03$, and the dilated time is $t = t_0\gamma = 2.2 \times 5.03 = 11$ μs. 0.44 μs divides by γ; 5.0 is γ itself.

19. D. The speed of light in a vacuum is the same for all observers in inertial frames of reference.

The two postulates are that the laws of physics are the same in all inertial frames, and that the speed of light in a vacuum is the same for all inertial observers. A contradicts the first; B is the Newtonian assumption that relativity overturns.

20. A. reduce the effect of the uncertainty in starting and stopping the stopwatch on the period

The reaction-time uncertainty (about ±0.2 s) applies once to the whole timing, so dividing by 10 reduces its effect on the period tenfold. A systematic error (for example, a stopwatch that runs slow) is not removed by repetition.

Section B — short answer

1. (5 marks in total)

a. $$a = \frac{F_{\text{net}}}{m} = \frac{1.0 \times 9.81}{3.0 + 1.0} = 2.45 \text{ m s}^{-2}$$

[2 marks]

Treat the blocks as one system: the only unbalanced external force is the weight of the hanging block, $1.0 \times 9.81 = 9.81$ N, acting on the total mass of 4.0 kg. 1 mark for identifying the net force, 1 mark for dividing by the total mass.

b. 7.36 N

[2 marks]

The tension is the only horizontal force on the 3.0 kg block: $T = ma = 3.0 \times 2.4525 = 7.36$ N. (Check with the hanging block: $9.81 - T = 1.0 \times 2.4525$.) 1 mark for the method, 1 mark for the answer. Common error: taking the tension to be the weight of the hanging block, 9.81 N.

c. The hanging block accelerates downwards, so the net force on it is downwards: its weight must be larger than the upward tension. [1 mark]

If the tension equalled the weight, the net force on the hanging block would be zero and it would not accelerate.

2. (7 marks in total)

a. Horizontal 14.7 m s⁻¹; vertical 10.3 m s⁻¹

[1 mark]

$18.0\cos(35.0^\circ) = 14.74$ m s⁻¹ and $18.0\sin(35.0^\circ) = 10.32$ m s⁻¹.

b. It reaches the wall after 1.70 s at a height of 3.40 m, so it clears the 2.40 m wall by about 1.0 m.

[3 marks]

Horizontal motion is uniform: $t = \frac{25.0}{14.74} = 1.696$ s. Vertically, $s = ut + \frac{1}{2}at^2 = 10.32 \times 1.696 - \frac{1}{2} \times 9.81 \times 1.696^2 = 3.40$ m. Marks: 1 for the time to reach the wall; 1 for the height; 1 for the comparison and conclusion. Common error: using the full 18.0 m s⁻¹ as the horizontal speed.

c. 5.43 m

[2 marks]

At the highest point the vertical velocity is zero: $v^2 = u^2 + 2as$ gives $0 = 10.32^2 - 2 \times 9.81 \times s$, so $s = 5.43$ m. 1 mark for the method, 1 mark for the answer.

d. 14.7 m s⁻¹ [1 mark]

Only the vertical component is zero at the top; the horizontal component is unchanged throughout the flight.

3. (6 marks in total)

a. 7200 N, directed down (towards the centre of the loop)

[2 marks]

$F_{\text{net}} = \frac{mv^2}{r} = \frac{400 \times 12^2}{8.0} = 7200$ N, towards the centre, which is vertically down at the top. 1 mark for the magnitude, 1 mark for the direction.

b. 3276 N (about 3.3 × 10³ N), downwards

[2 marks]

At the top both the weight and the normal force act downwards: $N + mg = \frac{mv^2}{r}$, so $N = 7200 - 400 \times 9.81 = 3276$ N. 1 mark for the force equation, 1 mark for the answer. Common error: subtracting the weight the other way, as if the car were at the bottom.

c. 8.86 m s⁻¹

[2 marks]

At the minimum speed the normal force is zero and gravity alone provides the centripetal force: $mg = \frac{mv^2}{r}$, so $v = \sqrt{gr} = \sqrt{9.81 \times 8.0} = 8.86$ m s⁻¹. 1 mark for setting $N = 0$, 1 mark for the value.

4. (5 marks in total)

a. 1.8 × 10⁴ N s

[2 marks]

Impulse $= m\Delta v = 1200 \times (0 - 15) = -18\,000$ N s; its magnitude is 18 000 N s, directed opposite to the car's initial motion. 1 mark for the change in momentum, 1 mark for the value.

b. 2.25 × 10⁵ N

[1 mark]

$F = \frac{m\Delta v}{\Delta t} = \frac{18\,000}{0.080} = 225\,000$ N.

c. The change in momentum (impulse) is fixed by the collision; by crumpling, the car takes longer to stop, and since $F\Delta t = m\Delta v$, a longer time means a smaller average force.

[2 marks]

1 mark for recognising that the impulse (change in momentum) is the same either way, 1 mark for linking the increased stopping time to the reduced force. Answers that say the crumple zone "absorbs the force" do not earn the second mark without the time argument.

5. (7 marks in total)

a.
$$r = \sqrt[3]{\frac{GM_E T^2}{4\pi^2}} = 2.66 \times 10^7 \text{ m}$$

[3 marks]

Gravity provides the centripetal force: $\frac{GM_E m}{r^2} = \frac{4\pi^2 mr}{T^2}$, so $r^3 = \frac{GM_E T^2}{4\pi^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times (43\,200)^2}{4\pi^2}$, giving $r = 2.66 \times 10^7$ m. Marks: 1 for equating gravitational and centripetal force; 1 for the period in seconds (43 200 s); 1 for the substitution. Common error: using the period in hours.

b. 3.87 × 10³ m s⁻¹

[2 marks]

$v = \frac{2\pi r}{T} = \frac{2\pi \times 2.66 \times 10^7}{43\,200} = 3.87 \times 10^3$ m s⁻¹ (equivalently $\sqrt{\frac{GM_E}{r}}$). 1 mark for the method, 1 mark for the value.

c. The astronaut and the station are both in free fall, accelerating towards Earth at the same rate, so the station exerts no normal force on the astronaut. [2 marks]

The sensation of weight comes from a normal (contact) force. In orbit the only force on both the astronaut and the station is gravity, so they accelerate together and nothing pushes on the astronaut: apparent weightlessness. 1 mark for "both in free fall with the same acceleration", 1 mark for "no normal force".

6. (5 marks in total)

a. 2.5×10^4 V m^{-1}

[1 mark]

$E = \frac{V}{d} = \frac{500}{0.020} = 25\,000$ V m^{-1} (equivalently N C^{-1}).

b. 4.0×10^{-15} N

[1 mark]

$F = qE = 1.60 \times 10^{-19} \times 25\,000 = 4.0 \times 10^{-15}$ N.

c. 1.33×10^7 m s^{-1}

[3 marks]

The work done by the field becomes kinetic energy: $\frac{1}{2}mv^2 = qV$, so

$v = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2\times1.60\times10^{-19}\times500}{9.11\times10^{-31}}} = 1.33 \times 10^7$ m s^{-1}. Marks: 1 for $qV = \frac{1}{2}mv^2$; 1 for the substitution; 1 for the answer. (Relativistic effects are negligible at this speed.)

7. (6 marks in total)

a. Into the page [1 mark]

The ions move right as they enter and are pushed towards the top of the page (towards the centre of their circle). For a positive charge, the right-hand rule then gives a field into the page.

b. 3.32×10^{-26} kg

[2 marks]

$r = \frac{mv}{qB}$, so $m = \frac{qBr}{v} = \frac{1.60\times10^{-19}\times0.50\times0.083}{2.0\times10^5} = 3.32 \times 10^{-26}$ kg (about 20 atomic mass units — neon-20). 1 mark for rearranging, 1 mark for the value with the radius in metres.

c. The magnetic force is always perpendicular to the velocity, so it does no work on the ions and their kinetic energy (and speed) stays constant. [2 marks]

1 mark for "force perpendicular to velocity", 1 mark for "no work done, so kinetic energy is unchanged".

d. They follow a semicircle of larger radius and strike the detector further from the entry point.

[1 mark]

$r = \frac{mv}{qB}$ is proportional to the mass.

8. (8 marks in total)

a. 0.60 N

[2 marks]

$F = nIlB = 50 \times 1.5 \times 0.040 \times 0.20 = 0.60$ N. 1 mark for the substitution with $n = 50$ and l in metres, 1 mark for the value. Common error: leaving out the number of turns.

b. Zero: the current in JK is parallel to the magnetic field. [2 marks]

The magnetic force on a conductor depends on the component of the field perpendicular to the current; JK runs from left to right, the same direction as the field. 1 mark for zero, 1 mark for the reason.

c. Out of the page. Side MJ is pushed into the page, so the two forces form a couple that turns the coil about its axis. [2 marks]

In KL the current flows down the page and the field points right; the right-hand rule gives a force out of the page. The current in MJ is in the opposite direction, so its force is into the page. Equal and opposite forces on opposite sides of the axis produce a turning effect even though the net force on the coil is zero. 1 mark for the direction, 1 mark for the explanation.

d. Every half-turn it reverses the current in the coil, so the forces on the sides reverse at the right moment and keep turning the coil the same way. [2 marks]

Once the plane of the coil passes perpendicular to the field, the side that was pushed out of the page is on the other side of the axis; without reversing the current, the forces would turn the coil back. 1 mark for "reverses the current each half-turn", 1 mark for linking this to continuous rotation in one direction.

9. (8 marks in total)

a. 3.0×10^{-3} Wb

[1 mark]

$\Phi_B = B_\perp A = 0.30 \times 0.010 = 3.0 \times 10^{-3}$ Wb, when the plane of the coil is perpendicular to the field.

b. 60 V

[2 marks]

In a quarter-turn ($\frac{1}{4} \times \frac{1}{50} = 0.0050$ s) the flux falls from 3.0×10^{-3} Wb to zero: $\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = 100 \times \frac{3.0\times10^{-3}}{0.0050} = 60$ V. 1 mark for the time of a quarter-turn, 1 mark for the EMF.

c. A sine curve starting at zero, with peaks of ±94 V and a period of 20 ms (two complete cycles by 40 ms).

[3 marks]

At $t = 0$ the flux is a maximum but is changing at the slowest rate, so the EMF is zero and the graph is a sine (not cosine) curve. Marks: 1 for the sine shape starting at zero; 1 for the period of 20 ms; 1 for peaks of ±94 V.

d. The output becomes DC: every negative half-cycle is inverted, giving a fluctuating EMF that is always in one direction, with the same peak and 10 ms between peaks. [2 marks]

1 mark for "DC / one direction (rectified)", 1 mark for keeping the peak value and the correct timing. Common error: describing a steady, constant DC voltage.

10. (8 marks in total)

a. 29.0 A

[2 marks]

The transmission voltage is $690 \times 20 = 13\,800$ V, so $I = \frac{P}{V} = \frac{400\,000}{13\,800} = 29.0$ A. 1 mark for the stepped-up voltage, 1 mark for the current.

b. 4.20×10^3 W

[2 marks]

$P_{\text{loss}} = I^2R = 29.0^2 \times 5.0 = 4.20 \times 10^3$ W — about 1% of the power generated. 1 mark for the formula with the line current, 1 mark for the value.

c. 1.37×10^4 V (13 655 V)

[1 mark]

$V_{\text{drop}} = IR = 29.0 \times 5.0 = 145$ V, so $13\,800 - 145 = 13\,655$ V.

d. The current would be 580 A, giving a loss of $I^2R = 1.68 \times 10^6$ W — more than the 400 kW generated — so no useful power could reach the town.

[3 marks]

$I = \frac{400\,000}{690} = 580$ A, $P_{\text{loss}} = 580^2 \times 5.0 = 1.68 \times 10^6$ W (equivalently, the voltage drop $IR = 2900$ V exceeds the 690 V supplied). Marks: 1 for the current; 1 for the loss; 1 for the conclusion that stepping up the voltage (reducing the current) is essential.

11. (7 marks in total)

a. 4.3×10^{-3} m (4.26 mm)

[2 marks]

$\Delta x = \frac{\lambda L}{d} = \frac{532\times10^{-9}\times2.0}{0.25\times10^{-3}} = 4.26 \times 10^{-3}$ m. 1 mark for the substitution with consistent units, 1 mark for the value.

b. 1.33×10^{-6} m

[2 marks]

Dark bands have a path difference of $\left(n + \frac{1}{2}\right)\lambda$; the first is at $\frac{1}{2}\lambda$, so the third is at $\frac{5}{2}\lambda = 2.5 \times 532 \times 10^{-9} = 1.33 \times 10^{-6}$ m. 1 mark for 2.5λ, 1 mark for the value. Common error: using 3.5λ (counting the central band as dark).

c. Bright and dark bands can only be explained by waves from the two slits superposing: in phase (constructive interference) at bright bands and half a wavelength out of phase (destructive interference) at dark bands. A particle model predicts two bright strips. [2 marks]

1 mark for linking the bands to constructive and destructive interference, 1 mark for noting that particles would not cancel to produce dark bands.

d. The bands spread further apart.

[1 mark]

Red light has a longer wavelength, and Δx is proportional to λ.

12. (7 marks in total)

a. 5.5×10^{14} Hz [1 mark]

The horizontal intercept: below this frequency no photoelectrons are emitted.

b. 2.28 eV

[2 marks]

$\phi = hf_0 = 4.14 \times 10^{-15} \times 5.5 \times 10^{14} = 2.28$ eV (the magnitude of the vertical intercept if the line is extended). 1 mark for $\phi = hf_0$, 1 mark for the value.

c. Planck's constant, h (about 4.1×10^{-15} eV s)

[1 mark]

$E_{k\,\max} = hf - \phi$ is a straight line of gradient h.

d. 5.4×10^5 m s^{-1}

[2 marks]

$E_{k\,\max} = 4.14 \times 10^{-15} \times 7.5 \times 10^{14} - 2.28 = 0.828$ eV $= 1.32 \times 10^{-19}$ J, so $v = \sqrt{\frac{2E_k}{m_e}} = 5.4 \times 10^5$ m s^{-1}. 1 mark for the kinetic energy in joules, 1 mark for the speed.

e. Each photon has energy $hf = 1.66$ eV, less than the 2.28 eV work function; one photon interacts with one electron, so brightness (more photons) does not help.

[1 mark]

The key idea is the one-photon-one-electron interaction: the energy of an individual photon, not the intensity, decides whether an electron can escape.

13. (5 marks in total)

a. $\lambda = \dfrac{h}{\sqrt{2m_e qV}} = 1.67 \times 10^{-10}$ m

[2 marks]

$E_k = qV = 1.60 \times 10^{-19} \times 54 = 8.64 \times 10^{-18}$ J; $p = \sqrt{2m_e E_k} = 3.97 \times 10^{-24}$ kg m s^{-1}; $\lambda = \frac{h}{p} = 1.67 \times 10^{-10}$ m. 1 mark for the momentum, 1 mark for the wavelength.

b. 7.4 keV

[2 marks]

The same pattern requires the same wavelength: $E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3.00 \times 10^8}{1.67 \times 10^{-10}} = 7.43 \times 10^3$ eV. 1 mark for equal wavelengths, 1 mark for the energy.

c. Diffraction depends only on the wavelength compared with the spacing of the atoms; equal wavelengths spread by the same amount.

[1 mark]

This is the evidence that electrons have a wave-like nature, with wavelength $\lambda = \frac{h}{p}$.

14. (6 marks in total)

a. 13.3 years

[1 mark]

$t = \frac{12\text{ ly}}{0.90c} = 13.3$ years.

b. 5.81 years

[2 marks]

$\gamma = \frac{1}{\sqrt{1-0.90^2}} = 2.29$. The crew's clock is present at both events, so it measures the proper time: $t_0 = \frac{t}{\gamma} = \frac{13.3}{2.29} = 5.81$ years. 1 mark for γ, 1 mark for the time.

c. 5.23 light-years

[2 marks]

The proper length (12 ly) is measured in the Earth–star frame; the crew measure a contracted length $L = \frac{L_0}{\gamma} = \frac{12}{2.29} = 5.23$ ly. (Check: $\frac{5.23}{0.90} = 5.81$ years.) 1 mark for identifying the proper length, 1 mark for the value.

d. The crew: the departure from Earth and the arrival at the star happen at the same place in the spacecraft's frame. [1 mark]

Proper time is measured by a clock present at both events.

15. (10 marks in total)

a. Independent: current I. Dependent: force F (the balance reading). Controlled: e.g. the length of wire in the field, the magnet (field strength), or keeping the wire perpendicular to the field.

[2 marks]

1 mark for the independent and dependent variables, 1 mark for a valid controlled variable.

b. 11.8 mN

[1 mark]

$F = 1.20 \times 10^{-3} \times 9.81 = 1.18 \times 10^{-2}$ N.

c. Five points lying close to a straight line through (or very near) the origin, rising to about 30 mN at 2.5 A.

[3 marks]

Marks: 1 for correctly plotted points; 1 for a single straight line of best fit (not joined dot to dot); 1 for the line passing close to the origin, as $F = nIlB$ predicts.

d. About 0.24 T (gradient ≈ 0.012 N A^{-1})

[2 marks]

Gradient $= \frac{\Delta F}{\Delta I} \approx \frac{0.0299}{2.50} = 0.0120$ N A^{-1} $= lB$ (with $n = 1$), so $B = \frac{0.0120}{0.050} = 0.24$ T. Accept 0.23–0.25 T from a sensible gradient. 1 mark for the gradient with units, 1 mark for B.

e. A systematic error: the effective length is less than 5.0 cm, so dividing by 5.0 cm gives a value of B that is too small.

[2 marks]

1 mark for “systematic”, 1 mark for the direction of the effect (underestimate of B). Repeating the trials would not reduce it.