Physics SL

IB SL — Question Bank

Q1.

Worked Example A1 — Braking car:

A car travelling at 24 m s^{-1} applies the brakes and decelerates uniformly at 6.0 m s^{-2}. Find: (a) the time to stop; (b) the stopping distance.

Given: $u = 24 \text{ m s}^{-1}, v = 0, a = -6.0 \text{ m s}^{-2}$

(a) Use $v = u + at$:

$$0 = 24 + (-6.0)t \implies t = \frac{24}{6.0} = 4.0 \text{ s}$$

(b) Use $v^2 = u^2 + 2as$:

$$0 = 24^2 + 2(-6.0)s \implies s = \frac{576}{12} = 48 \text{ m}$$

Q2.

Worked Example A2 — Projectile:

A ball is launched horizontally from a cliff of height 45 m at 20 m s^{-1}. Find the horizontal distance travelled. Take $g = 9.81 \text{ m s}^{-2}$.

Vertical (to find time of flight):

$$s = ut + \tfrac{1}{2}at^2 \implies 45 = 0 + \tfrac{1}{2}(9.81)t^2$$

$$t = \sqrt{\tfrac{2\times45}{9.81}} = \sqrt{9.17} \approx 3.03 \text{ s}$$

Horizontal:

$$x = u_x t = 20 \times 3.03 \approx 61 \text{ m}$$

Q3.

Worked Example B1 — Object on a slope:

A 5.0 kg block rests on a slope inclined at 30° to the horizontal. The coefficient of static friction is 0.60. Determine whether the block slides.

Weight components: $W_{\parallel} = mg\sin 30^{\circ} = 5.0 \times 9.81 \times 0.50 = 24.5\text{ N}$

Normal force: $N = mg\cos 30^{\circ} = 5.0 \times 9.81 \times 0.866 = 42.5\text{ N}$

Maximum static friction: $F_{s,\max} = \mu_s N = 0.60 \times 42.5 = 25.5\text{ N}$

Since $W_{\parallel} = 24.5\text{ N} < F_{s,\max} = 25.5\text{ N}$, the block does **not** slide.

Q4.

Worked Example C1 — Roller-coaster loop:

A roller-coaster car of mass 800 kg starts from rest at a height of 40 m. Assuming no friction, find the speed at the bottom of the drop.

Using conservation of energy:

$mgh = \frac{1}{2}mv^2$

$v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 40} = \sqrt{784.8} \approx 28\text{ m s}^{-1}$

Q5.

Worked Example D1 — Perfectly inelastic collision:

A 3.0 kg trolley moving at 4.0 m s^{-1} collides with a stationary 2.0 kg trolley and they stick together. Find the velocity after the collision.

$m_1u_1 + m_2u_2 = (m_1 + m_2)v$

$3.0 \times 4.0 + 2.0 \times 0 = 5.0 \times v$

$v = \frac{12.0}{5.0} = 2.4\text{ m s}^{-1}$

Check kinetic energy change:

$E_{k,\text{before}} = \frac{1}{2}(3.0)(4.0)^2 = 24\text{ J}$

$E_{k,\text{after}} = \frac{1}{2}(5.0)(2.4)^2 = 14.4\text{ J}$

Energy lost = 9.6 J (converted to thermal and sound energy — inelastic collision confirmed).

Q6.

Worked Example D2 — Explosion (recoil):

A stationary rifle of mass 3.5 kg fires a bullet of mass 0.010 kg at 400 m s^{-1}. Find the recoil velocity of the rifle.

Initial total momentum = 0 (system at rest).

$0 = m_{\text{bullet}}v_{\text{bullet}} + m_{\text{rifle}}v_{\text{rifle}}$

$0 = 0.010 \times 400 + 3.5 \times v_{\text{rifle}}$

$v_{\text{rifle}} = -\frac{4.0}{3.5} \approx -1.1 \text{ m s}^{-1}$

The negative sign means the rifle recoils in the opposite direction to the bullet.

Q7.

Worked Example E1 — Banked curve:

A road is banked at 15° for a curve of radius 80 m. Find the design speed.

$v = \sqrt{rg \tan\theta} = \sqrt{80 \times 9.81 \times \tan 15^\circ}$

$v = \sqrt{80 \times 9.81 \times 0.268} = \sqrt{210.4} \approx 14.5 \text{ m s}^{-1}$

Q8.

Worked Example F1 — Orbital speed:

Find the orbital speed of the International Space Station (ISS), orbiting at 400 km above Earth's surface.

Given: $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$, $M_E = 5.97 \times 10^{24} \text{ kg}$, $R_E = 6.37 \times 10^6 \text{ m}$

$r = R_E + h = 6.37 \times 10^6 + 4.00 \times 10^5 = 6.77 \times 10^6 \text{ m}$

$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.77 \times 10^6}}$

$v = \sqrt{\frac{3.98 \times 10^{14}}{6.77 \times 10^6}} = \sqrt{5.88 \times 10^7} \approx 7670 \text{ m s}^{-1} \approx 7.7 \text{ km s}^{-1}$

Q9.

Worked Example B1 — Heating water:

A kettle contains 1.5 kg of water initially at $18\ ^\circ\text{C}$. The specific heat capacity of water is 4200 J $\text{kg}^{-1}\text{K}^{-1}$. Calculate the energy needed to bring the water to boiling point (100 °C).

Given: $m = 1.5$ kg, $c = 4200$ J $\text{kg}^{-1}\text{K}^{-1}$, $\Delta T = 100 - 18 = 82$ K

$Q = mc\Delta T = 1.5 \times 4200 \times 82 = 517{,}000 \text{ J} = 517 \text{ kJ}$

Examiner tip: Units for c are always J $\text{kg}^{-1}\text{K}^{-1}$ — do not write $\text{J}/\text{kg}/\text{K}$ in an IB paper; use the $^{-1}$ superscript notation. Note ΔT in K equals ΔT in °C, so converting to Kelvin does not change ΔT — only the absolute temperature T needs converting (e.g., for gas laws).

Q10.

Worked Example B2 — Melting ice:

Calculate the total energy needed to convert 0.50 kg of ice at $-10\ ^{\circ}\mathrm{C}$ to liquid water at $20\ ^{\circ}\mathrm{C}$.

Use $c_{\text{ice}} = 2100\ \mathrm{J\ kg^{-1}K^{-1}}$, $L_f = 3.34 \times 10^5\ \mathrm{J\ kg^{-1}}$, $c_{\text{water}} = 4200\ \mathrm{J\ kg^{-1}K^{-1}}$.

Step 1 — heat ice from −10 °C to 0 °C:

$Q_1 = 0.50 \times 2100 \times 10 = 10{,}500\ \mathrm{J}$

Step 2 — melt ice at 0 °C:

$Q_2 = 0.50 \times 3.34 \times 10^5 = 167{,}000\ \mathrm{J}$

Step 3 — heat water from 0 °C to 20 °C:

$Q_3 = 0.50 \times 4200 \times 20 = 42{,}000\ \mathrm{J}$

Total: $Q = 10{,}500 + 167{,}000 + 42{,}000 = 219{,}500\ \mathrm{J} \approx 220\ \mathrm{kJ}$

Q11.

Worked Example B3 — Gas in a cylinder:

A fixed amount of ideal gas is enclosed in a cylinder. Initially, $T_1 = 300\ \mathrm{K}, p_1 = 1.0 \times 10^5\ \mathrm{Pa}$, and $V_1 = 2.0 \times 10^{-3}\ \mathrm{m}^3$. The gas is heated at constant volume until $T_2 = 450\ \mathrm{K}$.

(a) Find the final pressure p_2.

(b) Calculate the number of moles of gas.

(a) Using Gay-Lussac's Law (constant V):

$\frac{p_1}{T_1} = \frac{p_2}{T_2} \implies p_2 = p_1 \times \frac{T_2}{T_1} = 1.0 \times 10^5 \times \frac{450}{300} = 1.5 \times 10^5\ \mathrm{Pa}$

(b) Using $pV = nRT$:

$n = \frac{p_1 V_1}{RT_1} = \frac{1.0 \times 10^5 \times 2.0 \times 10^{-3}}{8.31 \times 300} = \frac{200}{2493} \approx 0.080\ \mathrm{mol}$

Q12.

Worked Example B4 — rms speed of a gas:

Calculate the rms speed of nitrogen molecules ($M_r = 0.028\ \mathrm{kg\ mol^{-1}}$) at $T = 300\ \mathrm{K}$.

Using $\frac{1}{2}mv_{\text{rms}}^2 = \frac{3}{2}kT$:

$v_{\text{rms}} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M_r}} = \sqrt{\frac{3 \times 8.31 \times 300}{0.028}} = \sqrt{\frac{7479}{0.028}} = \sqrt{267{,}000} \approx 517\ \mathrm{m\ s^{-1}}$

Note: $m = M_r / N_A$ for one molecule, so the formula can also be written $v_{\text{rms}} = \sqrt{3RT/M_r}$ using molar quantities.

Q13.

Worked Example C1 — Inverse square law:

A point source of sound has intensity $I_1 = 4.0\ \mathrm{W\ m^{-2}}$ at a distance $r_1 = 2.0\ \mathrm{m}$. Find the intensity at $r_2 = 6.0\ \mathrm{m}$.

$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2} = \frac{4.0}{36} = \frac{1}{9}$

$I_2 = \frac{4.0}{9} \approx 0.44\ \mathrm{W\ m^{-2}}$

Q14.

Worked Example C2 — Ambulance Doppler shift:

An ambulance siren emits sound at $f_s = 800\ \mathrm{Hz}$. The ambulance moves toward a stationary observer at $v_s = 30\ \mathrm{m\ s^{-1}}$. Speed of sound $v = 340\ \mathrm{m\ s^{-1}}$.

(a) Frequency heard as ambulance approaches:

$f' = 800 \times \frac{340+0}{340-30} = 800 \times \frac{340}{310} = 800 \times 1.097 \approx 878\ \mathrm{Hz}$

(b) Frequency heard as ambulance recedes:

$f' = 800 \times \frac{340}{340+30} = 800 \times \frac{340}{370} = 800 \times 0.919 \approx 735\ \mathrm{Hz}$

The observer hears the frequency drop from 878 Hz to 735 Hz as the ambulance passes.

Q15.

Worked Example C3 — Snell's Law:

A ray of light in air ($n_1 = 1.00$) strikes a glass surface ($n_2 = 1.50$) at an angle of incidence $\theta_1 = 40^\circ$.

(a) Find the angle of refraction θ_2.

$n_1 \sin\theta_1 = n_2 \sin\theta_2 \implies \sin\theta_2 = \frac{1.00 \times \sin 40^\circ}{1.50} = \frac{0.643}{1.50} = 0.429$

$\theta_2 = \arcsin(0.429) \approx 25.4^\circ$

The ray bends toward the normal on entering the denser glass — confirmed by $\theta_2 < \theta_1$.

(b) Calculate the critical angle for this glass–air interface.

At the critical angle, $\theta_2 = 90^\circ$, so $\sin\theta_c = n_2/n_1 = 1/n$ (for glass to air):

$\sin\theta_c = \frac{n_{\text{air}}}{n_{\text{glass}}} = \frac{1.00}{1.50} = 0.667 \implies \theta_c \approx 41.8^\circ$

Q16.

Worked Example C4 — Double-slit fringe spacing:

Light of wavelength $\lambda = 600\ \text{nm}$ passes through two slits separated by $d = 0.30\ \text{mm}$. The screen is $D = 2.0\ \text{m}$ away.

$s = \frac{\lambda D}{d} = \frac{600\times10^{-9}\times2.0}{0.30\times10^{-3}} = \frac{1.2\times10^{-6}}{3.0\times10^{-4}} = 4.0\times10^{-3}\ \text{m} = 4.0\ \text{mm}$

Q17.

Worked Example C5 — Harmonics in a string:

A guitar string of length $L = 0.64\ \text{m}$ has a wave speed $v = 256\ \text{m s}^{-1}$.

(a) Find the fundamental frequency.

$f_1 = \frac{v}{2L} = \frac{256}{2\times0.64} = \frac{256}{1.28} = 200\ \text{Hz}$

(b) What is the wavelength of the 3rd harmonic?

$\lambda_3 = \frac{2L}{3} = \frac{2\times0.64}{3} = \frac{1.28}{3} \approx 0.43\ \text{m}$

(c) Find f_3: $f_3 = 3f_1 = 3\times200 = 600\ \text{Hz}$, or $f_3 = v/\lambda_3 = 256/0.427 \approx 600\ \text{Hz}$.

Q18.

Worked Example D1.1 — Gravitational potential:

Calculate the gravitational potential at the surface of the Earth.

Given: $M_E = 5.97\times10^{24}\ \text{kg}$, $R_E = 6.37\times10^{6}\ \text{m}$, $G = 6.67\times10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$

$V = -\frac{GM}{r} = -\frac{6.67\times10^{-11}\times5.97\times10^{24}}{6.37\times10^{6}}$

$V = -\frac{3.98\times10^{14}}{6.37\times10^{6}} \approx -6.25\times10^{7}\ \text{J kg}^{-1}$

The negative value confirms that Earth's surface is a bound location — energy must be supplied to move a mass from here to infinity.

Q19.

Worked Example D1.2 — Orbital speed and period:

A satellite orbits the Earth at a height of 600 km. Calculate (a) its orbital speed and (b) its orbital period.

Data: $G = 6.67\times10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$, $M_E = 5.97\times10^{24}\ \text{kg}$, $R_E = 6.37\times10^{6}\ \text{m}$, orbital height $h = 600\ \text{km}$

$r = R_E + h = 6.37\times10^{6} + 6.00\times10^{5} = 6.97\times10^{6}\ \text{m}$

(a) Orbital speed:

$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67\times10^{-11}\times5.97\times10^{24}}{6.97\times10^{6}}} = \sqrt{5.71\times10^{7}} \approx 7560\ \text{m s}^{-1}$

(b) Orbital period:

$$T = \frac{2\pi r}{v} = \frac{2\pi \times 6.97 \times 10^6}{7560} \approx 5800 \text{ s} \approx 97 \text{ min}$$

Q20.

Worked Example D2.1 — Electric field between plates:

Two parallel plates are separated by $d = 4.0$ mm and connected to a 120 V supply. Calculate (a) the electric field strength between the plates, and (b) the force on an electron between the plates.

(a) Field strength:

$$E = \frac{V}{d} = \frac{120}{4.0 \times 10^{-3}} = 3.0 \times 10^4 \text{ V m}^{-1}$$

(b) Force on electron ($q = 1.60 \times 10^{-19}$ C):

$$F = qE = 1.60 \times 10^{-19} \times 3.0 \times 10^4 = 4.8 \times 10^{-15} \text{ N}$$

The force is directed toward the positive plate (opposite to E because the electron is negatively charged).

Q21.

Worked Example D2.2 — Hall voltage:

A copper strip of thickness $t = 0.20$ mm carries a current of 5.0 A in a magnetic field of $B = 0.15$ T perpendicular to the strip. The charge carrier density for copper is $n = 8.5 \times 10^{28} \text{ m}^{-3}$. Calculate the Hall voltage.

$$V_H = \frac{BI}{nqt} = \frac{0.15 \times 5.0}{8.5 \times 10^{28} \times 1.60 \times 10^{-19} \times 0.20 \times 10^{-3}}$$

$$V_H = \frac{0.75}{2.72 \times 10^6} \approx 2.8 \times 10^{-7} \text{ V} = 0.28\ \mu\text{V}$$

This extremely small voltage explains why Hall probes use semiconductor materials (small n) rather than metals — a smaller n gives a larger, more measurable V_H.

Q22.

Worked Example D3.1 — Deflection between plates:

A proton ($m = 1.67 \times 10^{-27}$ kg, $q = 1.60 \times 10^{-19}$ C) enters horizontally between parallel plates of length $L = 8.0$ cm with initial speed $v_0 = 2.0 \times 10^6 \text{ m s}^{-1}$. The electric field between the plates is $E = 5.0 \times 10^4 \text{ V m}^{-1}$, directed upward.

Acceleration:

$$a = \frac{qE}{m} = \frac{1.60 \times 10^{-19} \times 5.0 \times 10^4}{1.67 \times 10^{-27}} = \frac{8.0 \times 10^{-15}}{1.67 \times 10^{-27}} \approx 4.79 \times 10^{12} \text{ m s}^{-2}$$

Time inside the plates:

$$t = \frac{L}{v_0} = \frac{0.080}{2.0 \times 10^6} = 4.0 \times 10^{-8} \text{ s}$$

Vertical deflection:

$y = \frac{1}{2}at^2 = \frac{1}{2} \times 4.79 \times 10^{12} \times (4.0 \times 10^{-8})^2 = \frac{1}{2} \times 4.79 \times 10^{12} \times 1.6 \times 10^{-15} \approx 3.8 \times 10^{-3}\ \mathrm{m} = 3.8\ \mathrm{mm}$

Q23.

Worked Example D3.2 — Circular motion in a magnetic field:

An electron ($m = 9.11 \times 10^{-31}$ kg, $q = 1.60 \times 10^{-19}$ C) moves at $3.0 \times 10^7\ \mathrm{m\ s^{-1}}$ perpendicular to a magnetic field of $B = 0.040\ \mathrm{T}$. Find the radius of its circular path.

$r = \frac{mv}{qB} = \frac{9.11 \times 10^{-31} \times 3.0 \times 10^7}{1.60 \times 10^{-19} \times 0.040}$

$r = \frac{2.73 \times 10^{-23}}{6.40 \times 10^{-21}} \approx 4.3 \times 10^{-3}\ \mathrm{m} = 4.3\ \mathrm{mm}$

Q24.

Worked Example D3.3 — Velocity selector and mass spectrometer:

Ions of charge $q = 1.60 \times 10^{-19}$ C pass through a velocity selector where $E = 2.4 \times 10^4\ \mathrm{V\ m^{-1}}$ and $B_1 = 0.080\ \mathrm{T}$.

(a) Find the speed selected.

(b) The ions then enter a region with $B_2 = 0.15\ \mathrm{T}$ and travel in a semicircle of radius $r = 0.21\ \mathrm{m}$. Find the mass of the ions.

(a) $v = E/B_1 = (2.4 \times 10^4)/(0.080) = 3.0 \times 10^5\ \mathrm{m\ s^{-1}}$

(b) Rearranging $r = mv/(qB_2)$:

$m = \frac{qB_2r}{v} = \frac{1.60 \times 10^{-19} \times 0.15 \times 0.21}{3.0 \times 10^5} = \frac{5.04 \times 10^{-21}}{3.0 \times 10^5} \approx 1.68 \times 10^{-26}\ \mathrm{kg}$

This corresponds to approximately 10 atomic mass units ($1\ \mathrm{u} = 1.66 \times 10^{-27}$ kg), consistent with a boron-10 ion ($^{10}_{5}\mathrm{B}$).

Q25.

Worked Example E1 — Alpha decay of radium-226:

Radium-226 decays by alpha emission. Write the balanced nuclear equation.

$^{226}_{88}\mathrm{Ra} \rightarrow ^{222}_{86}\mathrm{Rn} + ^{4}_{2}\mathrm{He}$

Check: Mass numbers: $226 = 222 + 4$ ✓. Atomic numbers: $88 = 86 + 2$ ✓. The daughter nucleus is radon-222.

Q26.

Worked Example E2 — Beta-minus decay of carbon-14:

Carbon-14 decays by beta-minus emission (used in radiocarbon dating). Write the equation.

$^{14}_{6}\mathrm{C} \rightarrow^{14}_{7} \mathrm{N} +^{0}_{-1} e + \bar{\nu}_e$

Check: Mass numbers: $14 = 14 + 0$ ✓. Atomic numbers: $6 = 7 + (-1)$ ✓. The daughter nucleus is nitrogen-14.

Q27.

Worked Example E3 — Half-life calculation:

A radioactive source has an initial activity of $A_0 = 3200\ \mathrm{Bq}$ and a half-life of $t_{1/2} = 5.0\ \mathrm{days}$.

(a) Find the activity after 20 days.

20 days = 4 × $t_{1/2}$, so the activity halves four times:

$A = 3200 \times \left(\frac{1}{2}\right)^4 = 3200 \times \frac{1}{16} = 200\ \mathrm{Bq}$

(b) Find the decay constant λ (in s^{-1}).

$t_{1/2} = 5.0\ \mathrm{days} = 5.0 \times 86400 = 432000\ \mathrm{s}$

$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{432000} = 1.60 \times 10^{-6}\ \mathrm{s}^{-1}$

Q28.

Worked Example E4 — Binding energy of helium-4:

A $^{4}_{2}$He nucleus has a measured mass of $4.0015\ \mathrm{u}$.

$m_p = 1.0073\ \mathrm{u}, m_n = 1.0087\ \mathrm{u}$.

Mass of 2 protons + 2 neutrons:

$2(1.0073) + 2(1.0087) = 2.0146 + 2.0174 = 4.0320\ \mathrm{u}$

Mass defect:

$\Delta m = 4.0320 - 4.0015 = 0.0305\ \mathrm{u}$

Binding energy:

$E_B = 0.0305 \times 931.5 = 28.4\ \mathrm{MeV}$

Binding energy per nucleon:

$\frac{E_B}{A} = \frac{28.4}{4} = 7.1\ \mathrm{MeV\ nucleon}^{-1}$

Q29.

Worked Example E5 — Photoelectric effect:

Light of frequency $f = 8.0 \times 10^{14}$ Hz strikes a metal surface with work function $\phi = 2.0$ eV.

(a) Calculate $E_{K,\text{max}}$ in eV.

Photon energy: $E = hf = 6.63 \times 10^{-34} \times 8.0 \times 10^{14} = 5.30 \times 10^{-19}$ J

Convert to eV: $E = 5.30 \times 10^{-19} / 1.60 \times 10^{-19} = 3.31$ eV

$E_{K,\text{max}} = E - \phi = 3.31 - 2.00 = 1.31 \text{ eV} \approx 1.3 \text{ eV}$

(b) Find the threshold frequency f_0.

$f_0 = \frac{\phi}{h} = \frac{2.0 \times 1.60 \times 10^{-19}}{6.63 \times 10^{-34}} = \frac{3.20 \times 10^{-19}}{6.63 \times 10^{-34}} = 4.83 \times 10^{14}$ Hz

Q30.

Worked Example E6 — Hydrogen emission line:

An electron in hydrogen drops from $n = 3$ to $n = 1$ (Lyman series, UV). Calculate the wavelength of the emitted photon.

$E_3 = -\frac{13.6}{9} = -1.51$ eV $\qquad E_1 = -13.6$ eV

$E_{\text{photon}} = E_3 - E_1 = -1.51 - (-13.6) = 12.09$ eV

Convert to joules: $E = 12.09 \times 1.60 \times 10^{-19} = 1.934 \times 10^{-18}$ J

$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{1.934 \times 10^{-18}} = \frac{1.989 \times 10^{-25}}{1.934 \times 10^{-18}} = 1.03 \times 10^{-7} \text{ m} = 103 \text{ nm}$

This is in the UV region, consistent with the Lyman series.