Answer Key & Model Answers

Half-Yearly Examination — Class XII Physics (Book I)

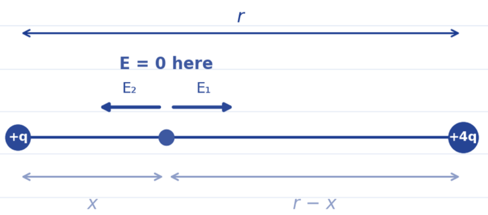
Session 2026–27 · Maximum Marks: 50

Each answer is written the way a student should set it out in the examination — the principle stated first, then the working step by step, with the diagram wherever one earns marks. All the arithmetic is done by hand; Appendix A collects the methods used.

SECTION A — Multiple Choice and Assertion-Reason (1 mark each)

1. (a) r/3

Let the null point be at a distance x from +q, between the charges. The two fields there point in opposite directions, so their magnitudes must be equal:



$$kq/x^2 = k(4q)/(r - x)^2 \implies (r - x)^2 = 4x^2$$
$$r - x = 2x \implies 3x = r \implies x = r/3$$

Take the positive square root only: x lies between the charges, so r − x is positive. Note also that between two LIKE charges the field vanishes but the potential never does, while between two UNLIKE charges the opposite is true. Read the question carefully to see which is being asked.

2. (b) Left charge negative, right charge positive

Field lines always begin on a positive charge and end on a negative one. In the figure the lines converge into the left charge and emerge from the right, so the left charge is negative and the right positive.

3. (b) 1 μF

For capacitors in series the reciprocals add:

$$1/C = 1/2 + 1/3 + 1/6 = (3 + 2 + 1)/6 = 6/6 = 1 \implies C = 1\ \mu F$$

Take the LCM (here 6) rather than converting to decimals — it keeps the arithmetic exact and is far quicker by hand.

4. (a) Both A and R are true and R is the correct explanation of A

Inside a conductor in electrostatic equilibrium $E = 0$. Since the potential difference between two points is $V_B - V_A = -\int E \cdot dl$, and E vanishes along every path inside the conductor, no work is done in carrying a charge from any interior point to the surface. The potential is therefore constant throughout and equal to its surface value.

5. (c) ~10^{-4} m/s

For an ordinary current of a few amperes in a copper wire of everyday cross-section, $v_d = I/(neA)$ works out at about 10^{-4} m/s — some 10^{10} times smaller than the random thermal speed of the electrons.

6. (b) P/Q = R/S

At balance no current flows through the galvanometer, so its two ends are at the same potential. Equating the potential drops in the two arms gives $P/Q = R/S$.

7. (c) 90°

$F = BIl \sin\theta$ is greatest when $\sin\theta = 1$, that is when the conductor is perpendicular to the field. (At $\theta = 0°$ or $180°$ the force is zero.)

8. (b) mB

Torque on a magnetic dipole is $\tau = mB \sin\theta$. With the axis perpendicular to B, $\theta = 90°$ and $\sin\theta = 1$, so $\tau = mB$ — the largest torque the field can exert on the magnet.

9. (a) opposes the motion of the magnet

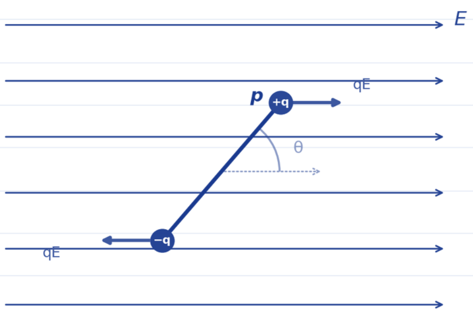
By Lenz's law the induced current opposes the change that produces it. As the magnet approaches, the flux through the coil increases; the induced current therefore circulates so as to present a like pole to the magnet and repel it. The work done against this repulsion is what appears as electrical energy in the coil — Lenz's law is conservation of energy in disguise.

10. (b) Both A and R are true, but R is NOT the correct explanation of A

R correctly establishes that E and B are non-zero, mutually perpendicular and in phase, which gives a non-zero Poynting vector $S = E \times B/\mu_0$ and so explains why the wave carries energy. Momentum transport, however, needs the further facts that the wave propagates in a definite direction and that $E = cB$, giving a momentum density S/c^2. R does not supply these, so although both statements are true, R explains only the energy, not the momentum.

SECTION B — Very Short Answer (2 marks each)

11. $\tau = 2 \times 10^{-4}$ N·m



Given $p = 4 \times 10^{-9}$ C·m, $E = 10^5$ N/C, $\theta = 30°$.

$$\tau = pE \sin\theta$$

Formula ... 1 mark

$$\tau = (4 \times 10^{-9})(10^5)(\sin 30°) = (4 \times 10^{-4})(0.5)$$

$$\tau = 2 \times 10^{-4}\ \text{N·m}$$

Substitution and answer … 1 mark

Collect the powers of ten first — $10^{-9} \times 10^{5} = 10^{-4}$ — and only then multiply the small numbers. Halving is easier than multiplying by 0.5, so read sin 30° = ½ as 'take half'.

12. Why resistivity rises with temperature

Resistivity is related to the relaxation time τ, the average interval between collisions of a free electron with the vibrating ion cores, by

$$\rho = m/(ne^2\tau)$$

Relation quoted … 1 mark

Raising the temperature increases the amplitude of vibration of the ion cores. The electrons therefore collide more frequently, so the relaxation time τ falls. Since $\rho \propto 1/\tau$, the resistivity — and with it the resistance — rises.

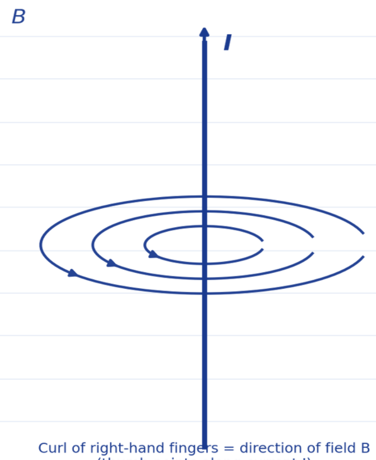
Explanation … 1 mark

Note carefully what does NOT change: n, the number density of free electrons, is essentially fixed in a metal. It is τ alone that responds to temperature. In a semiconductor n rises sharply with temperature and outweighs the fall in τ, which is why its resistivity falls instead.

13. Right-hand thumb rule

Grasp the conductor in the right hand with the thumb pointing along the direction of the current. The direction in which the fingers curl round the wire gives the direction of the magnetic field lines, which are concentric circles centred on the wire and lying in planes perpendicular to it.

Statement … 1 mark



Curl of right-hand fingers = direction of field B
(thumb points along current I)

Diagram … 1 mark

14. Parts of the electromagnetic spectrum

(i) Gamma rays — emitted in the radioactive decay of nuclei; used to destroy malignant tissue in the treatment of cancer tumours.

(ii) Microwaves — generated by klystrons and magnetrons; used in RADAR, because their short wavelength gives good angular resolution while still penetrating cloud and haze.

Both named … 1 mark

Order of increasing wavelength: gamma rays ($\sim 10^{-14}$–10^{-10} m) < microwaves ($\sim 10^{-3}$–10^{-1} m).

Order … 1 mark

SECTION C — Short Answer (3 marks each)

15. Field just outside a charged conducting plate

Gauss's theorem: the total electric flux through any closed surface equals $1/\varepsilon_0$ times the charge enclosed by it.

$$\oint E \cdot dS = q_{enclosed} / \varepsilon_0$$

By symmetry the field just outside a large plate is perpendicular to its surface and uniform. Choose a cylindrical Gaussian pillbox with one flat face of area A inside the metal and the other outside, parallel to the surface.

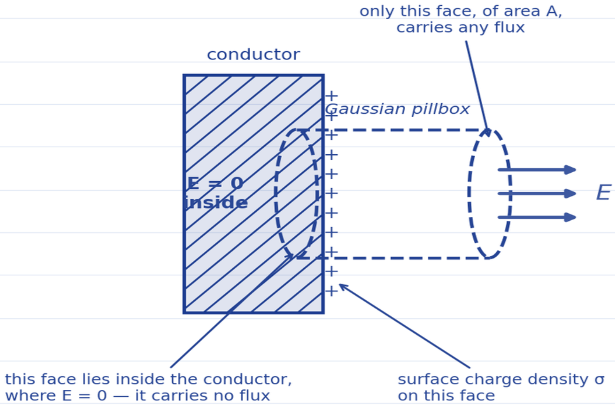


Diagram and choice of pillbox ... 1 mark

The face lying inside the conductor contributes nothing, because $E = 0$ everywhere inside a conductor in electrostatic equilibrium. The curved surface contributes nothing either, since E is parallel to it there. So the whole flux passes through the single outer face:

$$\Phi = EA$$

Flux ... 1 mark

The charge enclosed is that on the area A of the surface, $q = \sigma A$. Hence

$$EA = \sigma A/\varepsilon_0 \quad \Longrightarrow \quad E = \sigma/\varepsilon_0$$

directed normally outward from the plate (for $\sigma > 0$).

Result ... 1 mark

Do not confuse this with the thin non-conducting sheet, for which the pillbox straddles the sheet symmetrically, BOTH faces carry flux, and the result is $E = \sigma/2\varepsilon_0$. The factor of two comes entirely from how many faces of the pillbox the field passes through — one for a conductor, two for an insulating sheet. Always ask yourself which situation the question describes before choosing the pillbox.

16. Energy stored in a capacitor

Let q be the charge already on the capacitor at some stage of charging, when the potential difference across it is $V = q/C$. To transfer a further small charge dq against this potential difference the work needed is

$$dW = (q/C)\, dq$$

Element of work ... 1 mark

The total work done in charging from 0 to Q is therefore

$$U = \int_0^Q (q/C)\, dq = (1/C)[q^2/2]_0^Q$$
$$U = Q^2/2C = \tfrac{1}{2}CV^2$$

Integration and result ... 1 mark

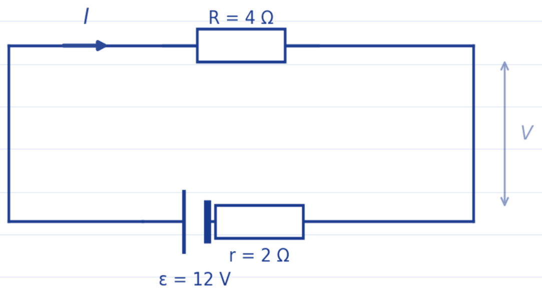
For a parallel plate capacitor $C = \varepsilon_0 A/d$ and $V = Ed$, so the energy per unit volume of the field is

$$u = U/(Ad) = ½(\varepsilon_0 A/d)(Ed)^2/(Ad) = ½\varepsilon_0 E^2$$

Energy density ... 1 mark

The factor ½ is easy to lose. It appears because the potential difference grows steadily from 0 to V as the capacitor charges, so the average p.d. against which the charge is moved is V/2, not V.

17. Cell with internal resistance



Given $\varepsilon = 12$ V, $r = 2\ \Omega$, $R = 4\ \Omega$.

(i) The emf drives current through the internal and external resistances in series:

$$I = \varepsilon/(R + r) = 12/(4 + 2) = 12/6 = 2\ A$$

Current ... 1 mark

(ii) The terminal potential difference is the emf less the drop inside the cell:

$$V = \varepsilon - Ir = 12 - (2)(2) = 12 - 4 = 8\ V$$

Terminal p.d. ... 1 mark

(iii) The same V must also appear across the external resistance:

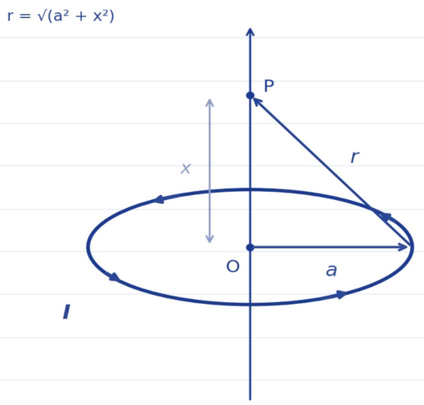
$$V = IR = (2)(4) = 8\ V$$

This agrees with part (ii), confirming that $\varepsilon = Ir + IR$ is satisfied.

Verification ... 1 mark

The terminal p.d. equals the emf only when I = 0, that is on open circuit. The larger the current drawn, the further V falls below ε — which is why a torch bulb dims as its cell ages and r grows.

18. Field on the axis of a circular loop



Biot–Savart law for a current element I dl at a point whose position vector from the element is r:

$$dB = (\mu_0/4\pi) \cdot I\ (dl \times \hat{r})/r^2$$

Law stated ... 1 mark

For a point P on the axis at distance x from the centre O, every element of the loop is at the same distance $r = \sqrt{(a^2 + x^2)}$ from P, and dl is perpendicular to r, so $\sin\theta = 1$:

$$|dB| = (\mu_0/4\pi) \cdot I\, dl/(a^2 + x^2)$$

Resolve dB into a component along the axis and one perpendicular to it. For every element there is a diametrically opposite element whose perpendicular component is equal and opposite, so those cancel in pairs and only the axial components survive. The axial component carries a factor $\cos\varphi = a/\sqrt{(a^2 + x^2)}$.

Symmetry argument ... 1 mark

$$B = \oint dB \cos\varphi = [\mu_0 I/4\pi(a^2 + x^2)] \cdot [a/\sqrt{(a^2 + x^2)}] \cdot \oint dl$$

and since $\oint dl = 2\pi a$,

$$B = \mu_0 I a^2 \,/\, [2(a^2 + x^2)^{(3/2)}]$$

directed along the axis, its sense given by the right-hand rule.

Result ... 1 mark

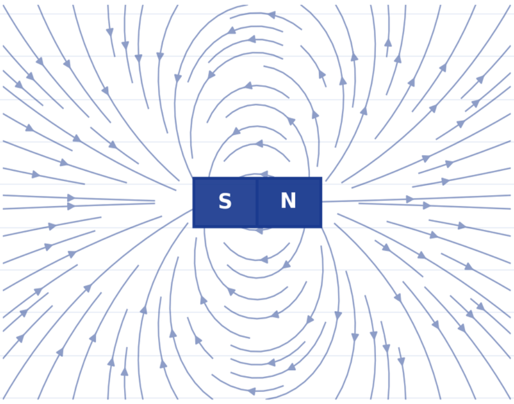
Check the special case: putting $x = 0$ gives $B = \mu_0 I/2a$, the familiar field at the centre of the loop. Any axial result should be tested this way — it costs one line and catches most algebraic slips.

19. Bar magnet as an equivalent solenoid

A current-carrying solenoid produces, outside itself, a field pattern with two poles and lines emerging from one end and entering the other — indistinguishable from the pattern of a bar magnet. The field of a solenoid at points far from it is that of a magnetic dipole whose moment is $m = NIA$. A bar magnet may therefore be replaced, for all external points, by an equivalent solenoid of the same magnetic moment.

Explanation ... 1 mark

Field lines of a bar magnet



Using this equivalence, for r much greater than the length of the magnet:

$$\text{(i) axial line:} \quad B_{axial} = (\mu_0/4\pi)(2m/r^3)$$

$$\text{(ii) equatorial line:} \quad B_{eq} = (\mu_0/4\pi)(m/r^3)$$

Both expressions ... 2 marks

$B_{axial} = 2\,B_{eq}$ at the same distance, and both fall off as $1/r^3$ — exactly the pattern of the electric dipole, where $E_{axial} = 2E_{eq}$. The parallel is worth remembering: it lets you carry results across from electrostatics.

20. Faraday's laws and motional emf

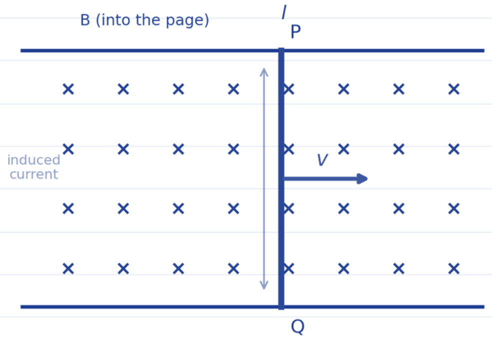
First law: whenever the magnetic flux linked with a closed circuit changes, an emf is induced in the circuit; it lasts only as long as the change continues.

Second law: the magnitude of the induced emf equals the rate of change of magnetic flux linkage,

$$\varepsilon = -N\, d\Phi_B/dt$$

the negative sign expressing Lenz's law.

Both laws ... 1 mark



Motional emf: let a rod of length l move with velocity v perpendicular to a uniform field B, the rod being perpendicular to both. Each free charge q in the rod experiences a magnetic force qvB along the rod, which drives charge to one end. Charge accumulates until the electric field E it sets up balances the magnetic force:

$$qE = qvB \implies E = vB$$

Force balance ... 1 mark

The emf is the work done per unit charge in taking a charge from one end of the rod to the other:

$$\varepsilon = E\,l = Bvl$$

Result ... 1 mark

The same result follows from flux: in time dt the rod sweeps an area $l\,v\,dt$, so $d\Phi = B\,l\,v\,dt$ and $\varepsilon = d\Phi/dt = Bvl$. Two routes to one answer is always worth showing.

SECTION D — Case Study (4 marks)

21. Resonance in a series LCR circuit

(i) At resonance the inductive and capacitive reactances are equal, $X_L = X_C$, that is $\omega_0 L = 1/\omega_0 C$. Hence

$$\omega_0 = 1/\sqrt{LC} \qquad \text{and} \qquad f_0 = 1/(2\pi\sqrt{LC})$$

1 mark

(ii) With $X_L = X_C$ the reactive terms cancel, so $Z = \sqrt{R^2 + (X_L - X_C)^2}$ reduces to $Z = R$, its least possible value. The circuit is then purely resistive and the current is exactly in phase with the applied voltage — the phase difference is zero.

1 mark

(iii) R_1 gives the sharper resonance. Sharpness is measured by the quality factor $Q = \omega_0 L/R$, which is inversely proportional to R, so the smaller resistance gives the taller and narrower peak. Both curves peak at the same f_0, since f_0 depends only on L and C.

1 mark

(iv) With $L = 0.5$ H and $C = 20$ μF:

$$LC = 0.5 \times 20 \times 10^{-6} = 10 \times 10^{-6} = 10^{-5}$$

Take the root by splitting off an even power of ten:

$$\sqrt{10^{-5}} = \sqrt{10 \times 10^{-6}} = \sqrt{10} \times 10^{-3} = 3.162 \times 10^{-3}$$

$$f_0 = 1/(2\pi \times 3.162 \times 10^{-3}) = 1/(19.87 \times 10^{-3})$$

Turn the division into a multiplication: $1/19.87 \approx 1/20 \times (1 + 0.0065) \approx 0.0503$.

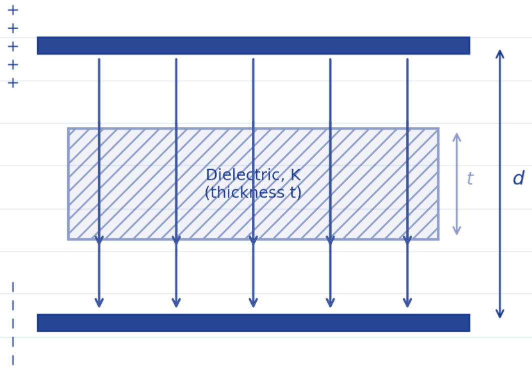
$$f_0 \approx 0.0503 \times 10^3 \approx 50.3 \text{ Hz}$$

1 mark

Never try to take $\sqrt{(10^{-5})}$ directly. Rewrite the index as an even power times a single digit — here 10×10^{-6} — so that the root of the power of ten is exact and only $\sqrt{10} = 3.162$ has to be remembered.

SECTION E — Long Answer (5 marks each)

22. Parallel plate capacitor with a dielectric slab



Without the slab, the field between the plates is $E_0 = \sigma/\varepsilon_0 = Q/(\varepsilon_0 A)$ and $C_0 = \varepsilon_0 A/d$.

Starting point … 1 mark

Now insert a slab of thickness t and dielectric constant K. Inside the dielectric the induced bound charges reduce the field to

$$E = E_0/K$$

while in the remaining air gap, of total thickness $(d - t)$, the field is still E_0.

Field inside the slab … 1 mark

The potential difference is the sum of the two contributions:

$$V = E_0(d - t) + (E_0/K)t = E_0[d - t + t/K]$$

$$V = (Q/\varepsilon_0 A)[d - t(1 - 1/K)]$$

Potential difference … 1 mark

Hence the capacitance is

$$C = Q/V = \varepsilon_0 A \;/\; [d - t(1 - 1/K)]$$

Result … 2 marks

Two checks. Putting $t = 0$ gives back $C = \varepsilon_0 A/d$, and putting $t = d$ gives $C = K\varepsilon_0 A/d = KC_0$. Note also that C does not depend on WHERE in the gap the slab sits — only on how thick it is.

OR

Potential energy of a system of point charges. The potential energy of a configuration is the work done in assembling it, bringing each charge in from infinity where the energy is taken as zero.

Bringing q_1 into empty space needs no work. Bringing q_2 from infinity to a distance r_{12} from q_1 means moving it through the potential $V_1 = (1/4\pi\varepsilon_0)(q_1/r_{12})$ due to q_1, so the work done is

$$U = (1/4\pi\varepsilon_0)\ (q_1 q_2/r_{12})$$

Two charges … 2 marks

For a third charge q_3 brought to distances r_{13} and r_{23} from the first two, the work is the sum of the work against each of them separately, since potentials add as scalars:

$$W_3 = (1/4\pi\varepsilon_0)[q_1 q_3/r_{13} + q_2 q_3/r_{23}]$$

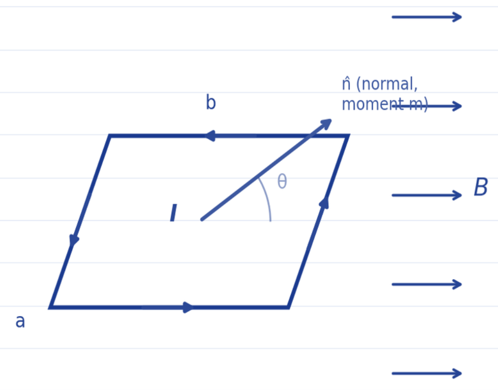
Adding the two stages gives the total potential energy of the three-charge system:

$$U = (1/4\pi\varepsilon_0)[\, q_1q_2/r_{12} + q_1q_3/r_{13} + q_2q_3/r_{23} \,]$$

Three charges … 3 marks

One term for every PAIR of charges — three pairs from three charges, six from four. Count the pairs before you start writing and you will not drop a term.

23. Torque on a current loop, and the moving coil galvanometer



Consider a rectangular loop of sides a and b, area $A = ab$, carrying current I in a uniform field B, with the normal to its plane making an angle θ with B.

The two sides of length b that are parallel to the axis of rotation carry current in opposite directions. Each experiences a force of magnitude

$$F = BIb$$

These two forces are equal and opposite but not collinear, so they constitute a couple.

Forces identified … 1 mark

The perpendicular distance between their lines of action is $a \sin\theta$, so the torque is

$$\tau = F \times (a \sin\theta) = BIb \cdot a \sin\theta = BIA \sin\theta$$

and for a coil of N turns,

$$\tau = NBIA \sin\theta = mB \sin\theta, \quad \text{where } m = NIA$$

Torque derived … 2 marks

Moving coil galvanometer. The coil is suspended in a radial magnetic field, produced by concave pole pieces together with a soft-iron cylinder. In such a field B always lies in the plane of the coil, so $\theta = 90°$ and $\sin\theta = 1$ whatever the deflection, and the deflecting torque is simply NIAB.

The suspension provides a restoring torque $k\varphi$ proportional to the deflection φ. At equilibrium the two balance:

$$NIAB = k\varphi \quad \Longrightarrow \quad \varphi = (NAB/k)\, I$$

Since $\varphi \propto I$, the deflection is directly proportional to the current and the scale is uniform. This is the working principle of the instrument.

Galvanometer … 2 marks

The radial field is not a refinement but the whole point: in an ordinary uniform field the torque would carry a factor sin θ, the deflection would not be proportional to I, and the scale would be crowded at one end.

OR

Self-inductance is the property of a coil by which it opposes any change in the current through itself. A changing current changes the flux the coil links with itself, inducing a back emf

$$\varepsilon = -L\, dI/dt, \qquad \text{equivalently} \quad L = N\Phi/I$$

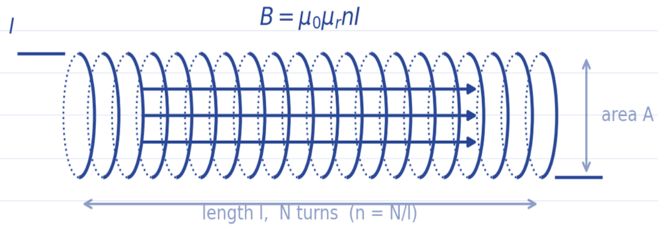
Self-inductance defined … 1 mark

Mutual inductance is the corresponding property of a PAIR of coils: a changing current in one induces an emf in the other,

$$\varepsilon_2 = -M\, dI_1/dt, \qquad M = N_2\Phi_2/I_1$$

Both are measured in henry (H).

Mutual inductance defined ... 1 mark



For a long solenoid of length l, cross-sectional area A and N turns, wound on a core of relative permeability μ_r, the field well inside is uniform:

$$B = \mu_0\mu_r\, n\, I = \mu_0\mu_r\, (N/l)\, I$$

Field inside ... 1 mark

The flux through one turn is $\Phi = BA$, and all N turns link it, so the total flux linkage is

$$N\Phi = \mu_0\mu_r\, (N^2A/l)\, I$$

Flux linkage ... 1 mark

Hence the self-inductance is

$$L = N\Phi/I = \mu_0\mu_r\, N^2A\, /\, l$$

Result ... 1 mark

Observe that L depends on N^2, not N: doubling the turns doubles both the field produced and the number of turns linking it. L is purely geometrical — it depends on the shape, size and core of the coil, never on the current flowing.

APPENDIX A — Working without a calculator

Calculators are not allowed, so the arithmetic must be arranged to suit the hand. These are the methods used in the answers above.

1. Turn every division into a multiplication

Memorise the reciprocal and multiply by it — a multiplication splits into easy parts, a long division does not.

$$V_0/\sqrt{2} = V_0 \times 0.707 \qquad I_{rms}\sqrt{2} = I_{rms} \times 1.414$$

Then split, e.g. $282 \times 0.707 = 282 \times 0.7 + 282 \times 0.007 = 197.4 + 1.974 = 199.4$.

2. Settle the powers of ten first

Do the exponents by inspection and leave a small mantissa to deal with. In Q11, $10^{-9} \times 10^{5} = 10^{-4}$ at once, leaving only 4×0.5 to compute. Before taking a root, rewrite the index as an EVEN power times a single digit:

$$\sqrt{(10^{-5})} = \sqrt{(10 \times 10^{-6})} = \sqrt{10} \times 10^{-3} = 3.162 \times 10^{-3}$$

3. Use the binomial approximation

For small x, $(1 + x)^n \approx 1 + nx$. This handles both awkward roots and awkward divisions.

$$\sqrt{50} = 7\sqrt{(1 + 1/49)} \approx 7(1 + 1/98) = 7.071$$

$$1/19.87 \approx (1/20)(1 + 0.0065) \approx 0.0503$$

Always pull perfect squares out of a surd before evaluating: $\sqrt{20000} = 100\sqrt{2} = 141.4$.

4. Factorise the divisor and divide in stages

An ugly divisor is often a product of two friendly ones. Clear the decimals, then cancel a factor.

$$3.2/9.1 = 32/91, \quad \text{and} \quad 91 = 7 \times 13$$

$$32/91 = (32 \div 13)/(91 \div 13) = 2.4615/7 = 0.3516$$

This route is exact, not approximate, so prefer it wherever a factor exists.

Divisors worth recognising: $91 = 7 \times 13$, $143 = 11 \times 13$, $119 = 7 \times 17$, $133 = 7 \times 19$, $121 = 11^2$, $169 = 13^2$. Also $1/7 = 0.142857$ recurring, $1/11 = 0.0909...$, $1/13 = 0.0769...$

5. Use the friendly forms of the constants

$$1/(4\pi\varepsilon_0) = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\varepsilon_0 = 1/(36\pi \times 10^9) \text{ F m}^{-1}, \quad \text{so} \quad 1/\varepsilon_0 = 36\pi \times 10^9$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}, \quad \text{so} \quad \mu_0/4\pi = 10^{-7}$$

Writing ε_0 as $1/(36\pi \times 10^9)$ beats 8.85×10^{-12}, because the π usually cancels against a π elsewhere and leaves a round number.

Constants worth knowing by heart

$$\sqrt{2} = 1.414 \qquad 1/\sqrt{2} = 0.707 \qquad \sqrt{3} = 1.732 \qquad 1/\sqrt{3} = 0.577$$

$$\sqrt{5} = 2.236 \qquad \sqrt{10} = 3.162 \qquad \pi = 3.142 \qquad 2\pi = 6.283 \qquad \pi^2 \approx 9.87$$

Finally, ask whether the answer is physically sensible. A speed above 3×10^8 m/s, a terminal p.d. greater than the emf, or a capacitance reduced by adding a dielectric all mean an arithmetic slip — catching it costs seconds.

— End of Answer Key —