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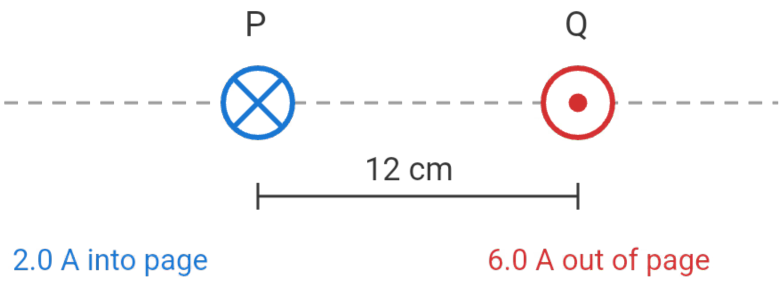
Secondary 5 - Physics

Magnetism, Induction and Circuits Challenge

Name: ______________________________

Class: ______________________________

1. Two very long straight parallel wires P and Q are perpendicular to the paper and are $12\,\mathrm{cm}$ apart. P carries $2.0\,\mathrm{A}$ into the paper and Q carries $6.0\,\mathrm{A}$ out of the paper.



Neglecting the Earth's magnetic field, at which point on the line joining the two wires (extended) is the resultant magnetic field zero?

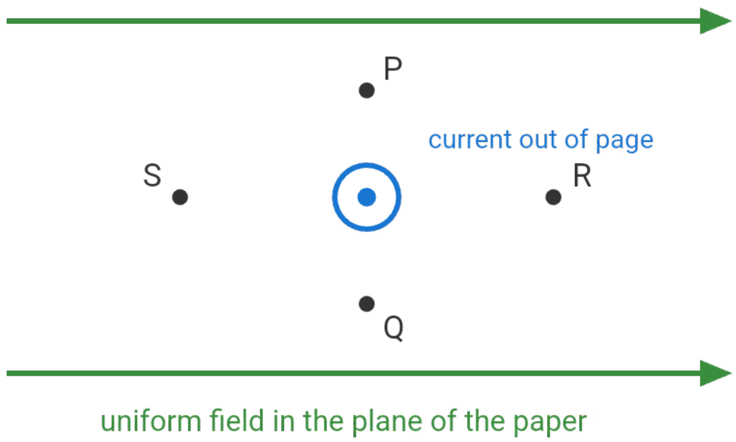
A. $6.0\,\mathrm{cm}$ from P, on the side away from Q

B. $3.0\,\mathrm{cm}$ from P, between P and Q

C. $6.0\,\mathrm{cm}$ from Q, on the side away from P

D. $4.0\,\mathrm{cm}$ from P, between P and Q

2. A long straight wire carries a steady current of $5.0\,\mathrm{A}$ out of the paper. It is placed in a uniform magnetic field of magnitude $2.0 \times 10^{-5}\,\mathrm{T}$ directed to the right in the plane of the paper. P, Q, R and S are four points around the wire.



Along which direction from the wire can the resultant magnetic field be zero, and at what distance from the wire?

A. Towards P, at $5.0\,\mathrm{cm}$ from the wire

B. Towards Q, at $5.0\,\mathrm{cm}$ from the wire

C. Towards P, at $10\,\mathrm{cm}$ from the wire

D. Towards R, at $2.5\,\mathrm{cm}$ from the wire

3. A very long air-cored solenoid is closely wound with 2000 turns per metre and carries a steady current I. A separate very long straight wire carries the same current I. At what perpendicular distance from the straight wire is the magnetic flux density equal to the flux density at the centre of the solenoid?

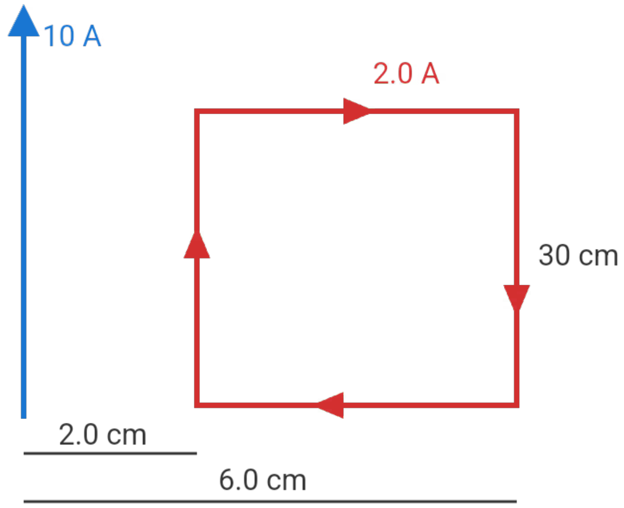
A. $8.0 \times 10^{-5}\,\mathrm{m}$

B. $1.6 \times 10^{-4}\,\mathrm{m}$

C. $4.0 \times 10^{-5}\,\mathrm{m}$

D. It cannot be found unless the value of I is given.

4. A long straight wire carries a current of $10\,\mathrm{A}$ upwards. A rectangular loop lies in the same plane as the wire and carries a current of $2.0\,\mathrm{A}$ in the sense shown. The two sides parallel to the wire are each $30\,\mathrm{cm}$ long and are at perpendicular distances $2.0\,\mathrm{cm}$ and $6.0\,\mathrm{cm}$ from the wire.



What is the magnitude and direction of the resultant magnetic force on the loop?

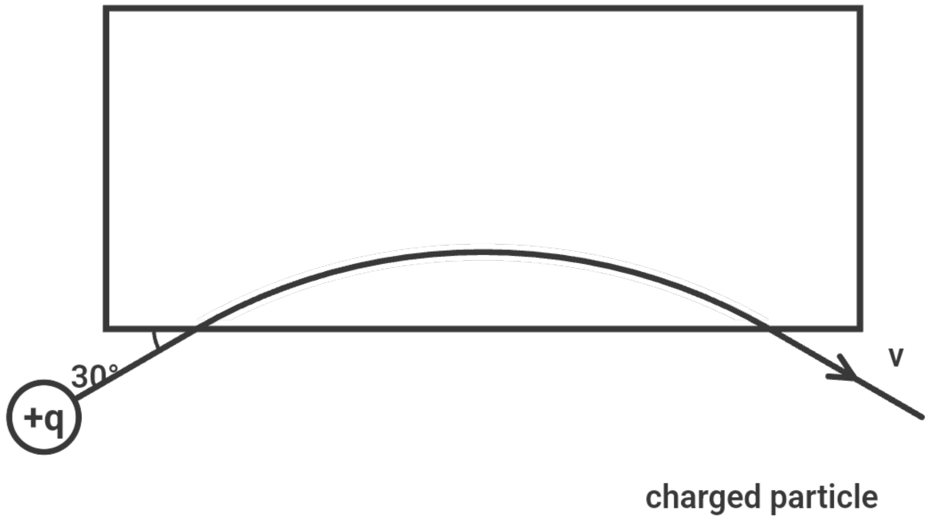
A. $4.0 \times 10^{-5}\,\mathrm{N}$, towards the wire

B. $4.0 \times 10^{-5}\,\mathrm{N}$, away from the wire

C. $8.0 \times 10^{-5}\,\mathrm{N}$, towards the wire

D. $6.0 \times 10^{-5}\,\mathrm{N}$, away from the wire

5. A positively charged particle enters a bounded region of uniform magnetic field through the lower boundary, travelling to the right at 30° above the horizontal. Inside the region it follows the circular arc shown and leaves again through the lower boundary. Gravity is negligible.



Which statement about the direction of the magnetic field and the speed of the particle as it leaves is correct?

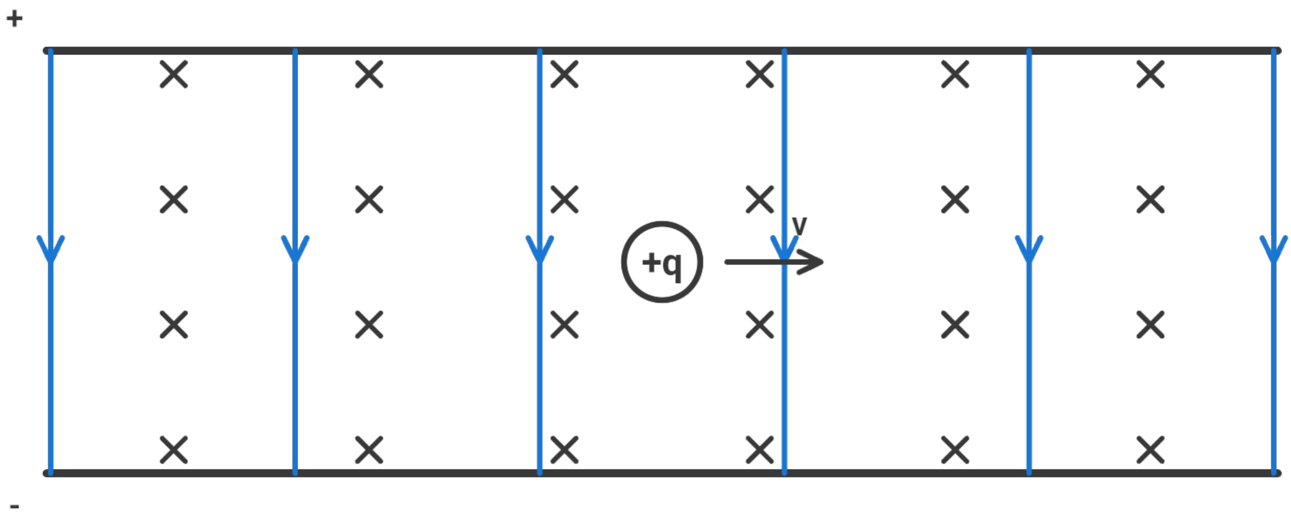
A. The field points out of the paper, and the speed on leaving equals the entry speed.

B. The field points into the paper, and the speed on leaving equals the entry speed.

C. The field points out of the paper, and the speed on leaving is smaller than the entry speed.

D. The field points into the paper, and the speed on leaving is smaller than the entry speed.

6. A velocity selector consists of two parallel plates separated by $4.0\,\mathrm{cm}$ with a uniform magnetic field of $0.025\,\mathrm{T}$ into the paper in the same region. A beam of positive ions travels horizontally to the right between the plates.



What potential difference must be applied across the plates so that ions of speed $3.0 \times 10^{5}\,\mathrm{m\,s^{-1}}$ pass through undeflected? Neglect gravity.

A. $300\,\mathrm{V}$

B. $7.5 \times 10^{3}\,\mathrm{V}$

C. $3.0 \times 10^{4}\,\mathrm{V}$

D. $1.9 \times 10^{5}\,\mathrm{V}$

7. A flat search coil of 50 turns and cross-sectional area $4.0\,\mathrm{cm}^{2}$ is held with its plane perpendicular to a uniform magnetic field of $0.80\,\mathrm{T}$. The coil is then turned through 180° about a diameter in a time of $0.050\,\mathrm{s}$, the field remaining unchanged. What is the average e.m.f. induced in the coil?

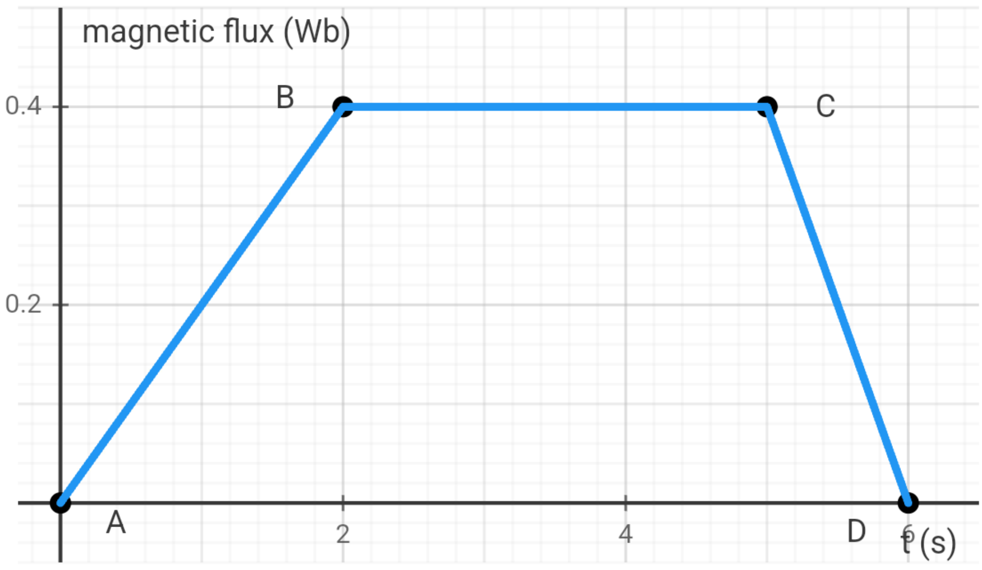
A. $0.64\,\mathrm{V}$

B. $0.32\,\mathrm{V}$

C. $1.28\,\mathrm{V}$

D. $0.064\,\mathrm{V}$

8. A coil of 100 turns is placed in a changing magnetic field. The graph shows how the magnetic flux through each turn of the coil varies with time.



Which statement is correct?

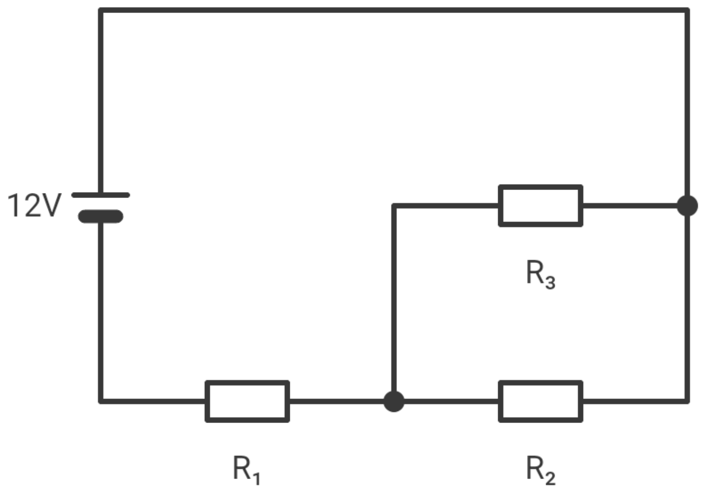
A. Between $5\,\mathrm{s}$ and $6\,\mathrm{s}$ the induced e.m.f. is $40\,\mathrm{V}$, opposite in direction to that between 0 and $2\,\mathrm{s}$.

B. Between $5\,\mathrm{s}$ and $6\,\mathrm{s}$ the induced e.m.f. is $40\,\mathrm{V}$, in the same direction as that between 0 and $2\,\mathrm{s}$.

C. Between $5\,\mathrm{s}$ and $6\,\mathrm{s}$ the induced e.m.f. is $20\,\mathrm{V}$, opposite in direction to that between 0 and $2\,\mathrm{s}$.

D. The induced e.m.f. is constant at $20\,\mathrm{V}$ throughout the whole $6\,\mathrm{s}$.

9. In the circuit below the battery has negligible internal resistance, $R_1 = 4\,\Omega$, $R_2 = 12\,\Omega$ and $R_3 = 6\,\Omega$.



Later R_2 develops a fault and becomes an open circuit. How does the p.d. across R_1 change?

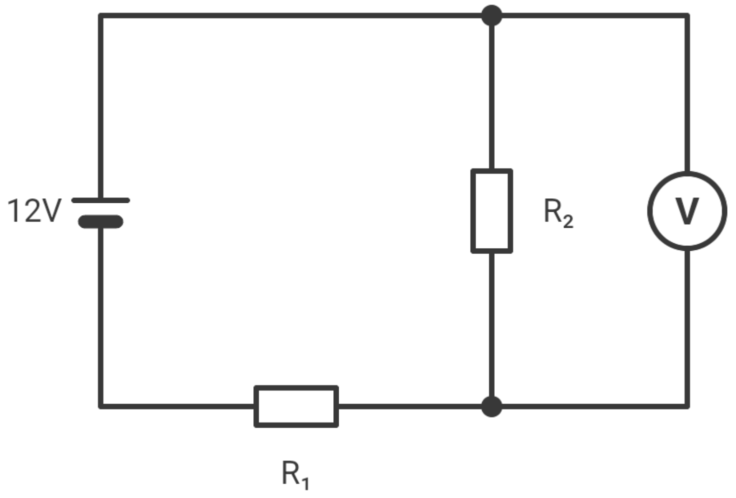
A. It decreases by $1.2\,\mathrm{V}$.

B. It increases by $1.2\,\mathrm{V}$.

C. It decreases by $2.4\,\mathrm{V}$.

D. It remains unchanged at $6.0\,\mathrm{V}$.

10. In the circuit below, R_1 and R_2 are each $10\,\mathrm{k\Omega}$ and the battery of e.m.f. $12\,\mathrm{V}$ has negligible internal resistance. The voltmeter connected across R_2 is not ideal: its resistance is $20\,\mathrm{k\Omega}$.



What is the reading of the voltmeter?

A. $4.8\,\mathrm{V}$

B. $6.0\,\mathrm{V}$

C. $7.2\,\mathrm{V}$

D. $3.6\,\mathrm{V}$

Answers

1 **A**

The field of a long straight wire is $B = \frac{\mu_0 I}{2\pi r}$, so the field is stronger nearer the wire and stronger for the larger current.
Because the two currents are in opposite directions, their fields point the same way at every point between the wires, so they can never cancel there. Cancellation is only possible outside the pair, and it must be on the side of the smaller current (wire P), so that the shorter distance can compensate for the smaller current.
Let the point be a distance x from P, on the far side from Q. Its distance from Q is $x + 12$:

$$\frac{\mu_0(2.0)}{2\pi x} = \frac{\mu_0(6.0)}{2\pi(x+12)}$$

$$\begin{aligned} 2.0(x+12) &= 6.0x \\ 2.0x + 24 &= 6.0x \\ 4.0x &= 24 \\ x &= 6.0 \end{aligned}$$

So the resultant field is zero at $6.0\,\mathrm{cm}$ from P, on the side away from Q.

2 A

For cancellation, the wire's own field must be equal in magnitude and opposite in direction to the uniform field, i.e. it must point to the left.
Apply the right-hand grip rule: with the current out of the paper, the field lines circle the wire anticlockwise. Directly above the wire (towards P) the tangential direction of an anticlockwise circle is to the left, which is exactly what is needed. Below the wire it points to the right, and at R and S the wire's field is vertical, so it can never cancel a horizontal field there.

Now find the distance using $B = \frac{\mu_0 I}{2\pi r}$:

$$\begin{aligned} r &= \frac{\mu_0 I}{2\pi B} \\ &= \frac{(4\pi \times 10^{-7})(5.0)}{2\pi(2.0 \times 10^{-5})} \\ &= \frac{(2 \times 10^{-7})(5.0)}{2.0 \times 10^{-5}} \\ &= \frac{1.0 \times 10^{-6}}{2.0 \times 10^{-5}} \\ &= 0.050\,\mathrm{m} \end{aligned}$$

So the field is zero at $5.0\,\mathrm{cm}$ directly above the wire, at P's side.

3 A

Write both flux densities with the same current I.
Centre of a long solenoid: $B_{\text{sol}} = \mu_0 n I$ with $n = 2000\,\mathrm{m}^{-1}$.

Long straight wire: $B_{\text{wire}} = \frac{\mu_0 I}{2\pi r}$.

Setting them equal, the current I and μ_0 cancel, so the answer does not depend on the current at all:

$$\begin{aligned} \mu_0 n I &= \frac{\mu_0 I}{2\pi r} \\ n &= \frac{1}{2\pi r} \\ r &= \frac{1}{2\pi n} \\ r &= \frac{1}{2\pi(2000)} \\ r &= 7.96 \times 10^{-5}\,\mathrm{m} \end{aligned}$$

So the required distance is about $8.0 \times 10^{-5}\,\mathrm{m}$.

4 **A**

The force per unit length between long parallel currents gives, for a side of length l at distance d:

$$F = \frac{\mu_0 I_1 I_2 l}{2\pi d} = \frac{(2 \times 10^{-7}) I_1 I_2 l}{d}$$

The two sides perpendicular to the wire carry currents in opposite senses at equal average distances, so their forces cancel. Only the two parallel sides matter.

Near side ($d = 0.020\,\mathrm{m}$), current is in the same direction as the wire's current, so it is attracted:

$$F_1 = \frac{(2 \times 10^{-7})(10)(2.0)(0.30)}{0.020} = 6.0 \times 10^{-5}\,\mathrm{N}$$

Far side ($d = 0.060\,\mathrm{m}$), current is opposite, so it is repelled:

$$F_2 = \frac{(2 \times 10^{-7})(10)(2.0)(0.30)}{0.060} = 2.0 \times 10^{-5}\,\mathrm{N}$$

The two forces are opposite, so the resultant is

$$F = 6.0 \times 10^{-5} - 2.0 \times 10^{-5} = 4.0 \times 10^{-5}\,\mathrm{N}$$

directed towards the wire, because the attraction on the nearer side dominates.

5 **A**

First find the direction of the centripetal force. The arc bulges upwards, so the centre of the circle lies below the arc. At the highest point of the path the velocity is horizontal and to the right, and the force must point downwards (towards the centre).

Now apply $\vec{F} = q\vec{v} \times \vec{B}$ for a positive charge with $\vec{v}$ to the right and $\vec{F}$ downwards.

Using the right hand: fingers point right ($\vec{v}$), and the palm must push downwards.

This requires $\vec{B}$ to point out of the paper. (A field into the paper would give an upward force and bend the path the other way.)

For the speed: the magnetic force is always perpendicular to the velocity, so it does no work on the particle. The kinetic energy, and hence the speed, is unchanged when the particle leaves the field.

6 A

For the ions to travel straight, the electric force must exactly balance the magnetic force:

$qE = qvB \quad \Rightarrow \quad E = vB$

Note the charge cancels, which is why a velocity selector picks out one speed regardless of charge or mass.

$E = (3.0 \times 10^5)(0.025) = 7.5 \times 10^3\,\mathrm{V\,m^{-1}}$

For parallel plates, $E = \dfrac{V}{d}$, so with $d = 0.040\,\mathrm{m}$:

$$\begin{aligned} V &= Ed \\ &= (7.5 \times 10^3)(0.040) \\ &= 300\,\mathrm{V} \end{aligned}$$

So a p.d. of $300\,\mathrm{V}$ is required. Remember to convert the separation into metres before using $E = V/d$.

7 A

Use Faraday's law with the change of flux linkage: $\mathcal{E} = N\dfrac{\Delta\Phi}{\Delta t}$.

First convert the area: $A = 4.0\,\mathrm{cm^2} = 4.0 \times 10^{-4}\,\mathrm{m^2}$.

Initially the flux through one turn is $+BA$. After turning through 180° the same face is linked by flux in the opposite sense, so the flux becomes $-BA$. The change is therefore twice BA, not just BA:

$$\begin{aligned} \Delta\Phi &= 2BA \\ &= 2(0.80)(4.0 \times 10^{-4}) \\ &= 6.4 \times 10^{-4}\,\mathrm{Wb} \end{aligned}$$

Then

$$\begin{aligned} \mathcal{E} &= N\frac{\Delta\Phi}{\Delta t} \\ &= 50 \times \frac{6.4 \times 10^{-4}}{0.050} \\ &= 50 \times 1.28 \times 10^{-2} \\ &= 0.64\,\mathrm{V} \end{aligned}$$

8 A

Faraday's law gives $\mathcal{E} = N\dfrac{\Delta\Phi}{\Delta t}$, so the induced e.m.f. is N times the gradient of the flux-time graph, and the sign of the gradient fixes the direction of the induced current.
From A to B the flux rises from 0 to $0.4\,\mathrm{Wb}$ in $2\,\mathrm{s}$:

$$\mathcal{E} = 100 \times \frac{0.4}{2} = 20\,\mathrm{V}$$

From B to C the graph is flat, so the gradient is zero and no e.m.f. is induced.
From C to D the flux falls from $0.4\,\mathrm{Wb}$ to 0 in $1\,\mathrm{s}$:

$$\mathcal{E} = 100 \times \frac{0.4}{1} = 40\,\mathrm{V}$$

Because the flux is now decreasing instead of increasing, the gradient has the opposite sign, so by Lenz's law the induced current (and e.m.f.) is in the opposite direction to that during the first interval.
The graph is not a straight line of constant gradient throughout, so the e.m.f. is certainly not constant over the whole $6\,\mathrm{s}$.

9 A

Before the fault: R_2 and R_3 are in parallel.

$$\begin{aligned} R_\mathrm{p} &= \frac{12 \times 6}{12 + 6} \\ &= 4\,\Omega \end{aligned}$$

Total resistance $= 4 + 4 = 8\,\Omega$, so the current from the battery is

$$I = \frac{12}{8} = 1.5\,\mathrm{A}$$

and the p.d. across R_1 is $V_1 = (1.5)(4) = 6.0\,\mathrm{V}$.
After R_2 goes open circuit: no current can pass through that branch, so only R_3 remains in series with R_1.

$$\begin{aligned} R_\text{total} &= 4 + 6 = 10\,\Omega \\ I' &= \frac{12}{10} = 1.2\,\mathrm{A} \\ V_1' &= (1.2)(4) = 4.8\,\mathrm{V} \end{aligned}$$

Removing a parallel branch increases the total resistance, so the main current falls and the p.d. across the series resistor falls:
$6.0 - 4.8 = 1.2\,\mathrm{V}$ decrease.

10 **A**

A real voltmeter draws current, so it must be treated as a resistor in parallel with the component it measures. This is the loading effect.
Combined resistance of R_2 and the voltmeter:

$$\begin{aligned} R_\mathrm{p} &= \frac{(10)(20)}{10+20} \\ &= \frac{200}{30} \\ &= 6.67\,\mathrm{k}\Omega \end{aligned}$$

Now the circuit is simply R_1 in series with R_p, so use the potential divider rule:

$$\begin{aligned} V &= 12 \times \frac{R_\mathrm{p}}{R_1 + R_\mathrm{p}} \\ &= 12 \times \frac{6.67}{10+6.67} \\ &= 12 \times \frac{200/30}{500/30} \\ &= 12 \times 0.4 \\ &= 4.8\,\mathrm{V} \end{aligned}$$

The voltmeter reads $4.8\,\mathrm{V}$, lower than the $6.0\,\mathrm{V}$ that would exist without the meter connected.