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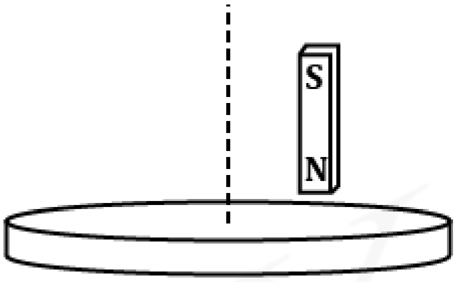
Date: 21/11/2021

Subject: Physics

Topic : Electromagnetic Induction   Class: Standard XII

1. A light disc made of Aluminium (a nonmagnetic material) is kept horizontally and is free to rotate about its axis, as shown in the figure. A strong magnet is held vertically at a point above the disc away from its axis. On revolving the magnet about the axis of the disc, the disc will (figure is schematic and not drawn to scale)



- ✗ **A.** Rotate in the direction opposite to the direction of magnet's motion
- ✓ **B.** Rotate in the same direction as the direction of magnet's motion
- ✗ **C.** Not rotate and its temperature will remain unchanged
- ✗ **D.** Not rotate, but its temperature will slowly rise

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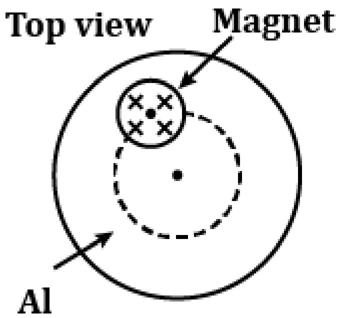
As the magnet rotates about the axis of the disc, the magnetic flux linked with the part of the disc lying just below the magnet will decrease. According to Lenz's law the disc will rotate in the direction of the rotation of the magnet to compensate for the decreasing magnetic flux.

Hence, the disc will rotate in the same direction as the direction of the rotation of the magnet.



Alternate method :
By Lenz's law, the disc also tries to move in the same direction because in the backward part of the disc the flux reduces as the magnet moves and as there is change in magnetic flux, so there is eddy current production which leads to production of heat These currents are such that it opposes the relative motion. So, disc will rotate in the direction of rotation of magnet.

Hence, option (B) is correct.

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2. A metal wheel with 8 metallic spokes, each $40\ \mathrm{cm}$ long, is rotated at a speed of $120\ \mathrm{rev/min}$ in a plane perpendicular to earth's magnetic field of $0.3 \times 10^{-4}\ \mathrm{T}$. Find the magnitude of the induced emf between the axis and the rim of the wheel (approximately).

✔ **A.** $3 \times 10^{-5}\ \mathrm{V}$

✖ **B.** $24 \times 10^{-5}\ \mathrm{V}$

✖ **C.** $0.37 \times 10^{-5}\ \mathrm{V}$

✖ **D.** $6 \times 10^{-5}\ \mathrm{V}$

The emf developed between the ends of a spoke is given by

$$\mathcal{E} = \frac{1}{2}B\omega l^2$$

Here $\omega = 120\ \frac{\mathrm{rev}}{\mathrm{min}} = 120 \times \frac{2\pi}{60}\mathrm{rad/s}$

$$\Rightarrow \omega = 4\pi\ \mathrm{rad/s}$$

$$\therefore \mathcal{E} = \frac{1}{2} \times 0.3 \times 10^{-4} \times 4\pi \times (0.4)^2$$

$$\Rightarrow \mathcal{E} = 0.096\pi \times 10^{-4}$$

$$\Rightarrow \mathcal{E} \approx 3 \times 10^{-5}\ \mathrm{V}$$

The same emf is induced between the ends of each spoke because all the spokes in the wheel are joined in parallel.

Hence,
$$\text{emf between rim and axle} = \text{emf across each spoke}$$

$$= 3 \times 10^{-5}\ \mathrm{V}$$

Hence, option (A) is correct.

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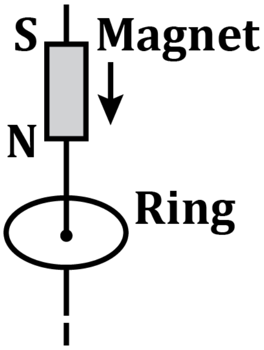
3. Consider a metal ring kept on a horizontal plane. A bar magnet is held above the ring with its length along the axis of the ring. If the magnet is dropped freely, the acceleration of the falling magnet is:
(g is acceleration due to gravity)



A. More than g

B. Equal to g

C. Less than g ✓

D. Depend on mass of magnet

As the magnet falls, the magnetic flux linked with the ring increases. According to the Lenz's law, the induces current in the ring will be in such a way that it will oppose the motion of the falling magnet i.e. the magnet will face retardation. Hence, the magnet falls with an acceleration less than g, i.e. $a < g$.

Also, the direction of current in the ring will be anti-clockwise, as seen by an observer above the ring.

Hence, option (C) is the correct answer.

Why this Question?
Key point: The direction of induced current is such that it opposes the relative motion between the ring and the magnet.

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4. The ends of a coil, having 20 turns, area of cross-section 1 cm^2 and resistance $2\ \Omega$, are connected to a galvanometer of resistance $40\ \Omega$. The plane of coil is inclined at an angle 30° to the direction of a magnetic field of intensity 1.5 T. The coil is quickly pulled out of the field, to a region of zero magnetic field. Calculate the total charge that passes through the galvanometer, during this interval.

- ✔ **A.** $35.7\ \mu\text{C}$
- ✘ **B.** $357\ \mu\text{C}$
- ✘ **C.** $3.57\ \mu\text{C}$
- ✘ **D.** $375\ \mu\text{C}$

Given,

$N = 20 \text{ turns}$
$A = 1 \text{ cm}^2 = 10^{-4} \text{ m}^2$
$R = 2 + 40 = 42\ \Omega$
$B = 1.5 \text{ T}$
$\theta = 90^\circ - 30^\circ = 60^\circ$

Total flux linked with the coil having turns N and area A is:

$$\phi_1 = N(\vec{B}\,.\,\vec{A}) = NBA\cos\theta$$

Initial flux, $\phi_1 = NBA\cos 60^\circ$

$$\phi_1 = \frac{NBA}{2}$$

When the coil is pulled out of the field, the flux becomes zero,

$\therefore$ Final flux, $\phi_2 = 0$

So, the change in flux is,

$$|\Delta\phi| = \frac{NBA}{2}$$

The charge flowed through circuit is:

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$$q=\frac{\Delta\phi}{R}=\frac{NBA}{2R}$$

$$\Rightarrow q=\frac{20\times1.5\times10^{-4}}{2\times42}$$

$$\therefore\quad q=0.357\times10^{-4}C=35.7\,\mu\text{C}$$

Hence, option (A) is the correct answer.

Why this Question?
Short Trick: To solve these type of questions, we can use the following expression for charge flown,

$$q=\frac{\Delta\phi}{R}$$

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5. A conducting loop of area $5.0\ \mathrm{cm}^2$ is placed in a magnetic field which varies sinusoidally with time as $B = B_0 \sin \omega t$ where $B_0 = 0.20\ \mathrm{T}$ and $\omega = 300\ s^{-1}$. The normal to the coil makes an angle of 60° with direction of the field. Find the maximum emf induced in the coil.

A. $1.5\ \mathrm{V}$

B. $0.15\ \mathrm{V}$

C. $0.015\ \mathrm{V}$ ✔

D. $3\ \mathrm{V}$

Area of the loop $(A) = 5 \times 10^{-4} \mathrm{m}^2$

$B = 0.2 \sin 300t$

$\theta = 60^\circ$

$\therefore$ Flux linked with the loop:

$\phi = BA \cos \theta$

$\phi = 0.2 \sin 300t \times 5 \times 10^{-4} \times \cos 60^\circ$

$\phi = 5 \times 10^{-5} \sin 300t$

Now, emf indcued in the loop is,

$$\mathcal{E} = \left|\frac{d\phi}{dt}\right| = 5 \times 10^{-5} \frac{d}{dt}(\sin 300t)$$

$\mathcal{E} = 5 \times 10^{-5} \times 300 \cos 300t$

$\Rightarrow \mathcal{E} = 15 \times 10^{-3} \cos 300t$

For maximum emf $\cos 300t = 1$

$\Rightarrow \mathcal{E}_{max} = 1.5 \times 10^{-2}\ \mathrm{V} = 0.015\ \mathrm{V}$

Hence, option (C) is the correct answer.

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6. A $10\ \mathrm{m}$ wide spacecraft moves through the interstellar space at a speed $3 \times 10^{7}\ \mathrm{ms}^{-1}$. A magnetic field of $B = 3 \times 10^{-10}\ \mathrm{T}$ exists in the space in a direction perpendicular to the spacecraft motion. Treating the spacecraft as a conductor, find the emf induced across its width.

   - ✗ **A.** $0.5\ \mathrm{V}$
   - ✓ **B.** $0.09\ \mathrm{V}$
   - ✗ **C.** $1\ \mathrm{V}$
   - ✗ **D.** $2.05\ \mathrm{V}$

Given,
$l = 10\ \mathrm{m};\ v = 3 \times 10^{7}\ \mathrm{ms}^{-1}\ ;\ B = 3 \times 10^{-10}\ \mathrm{T}$

Wide spacecraft can be treated as a single conductor moving in a magnetic field.

Therefore, induced emf across its width is,

$\mathcal{E} = Bvl$

$= 3 \times 10^{-10} \times 3 \times 10^{7} \times 10$

$\mathcal{E} = 9 \times 10^{-2}\ \mathrm{V} = 0.09\ \mathrm{V}$

Hence, (B) is the correct answer.

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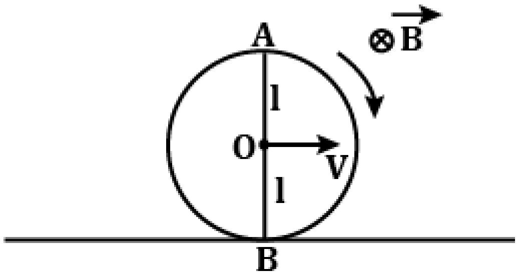
7. A wheel with a rod of length $2l$ attached along its diameter is rolling without slipping on a horizontal plane in a magnetic field B as shown in the figure. The velocity of the centre of the wheel is v. What is the emf developed across the ends of the rod AB ?



A. Bvl

B. $2Bvl$ ✓

C. $4Bvl$

D. 0

Since the wheel is rolling without slipping, we can say that the velocity of the top most point A is,

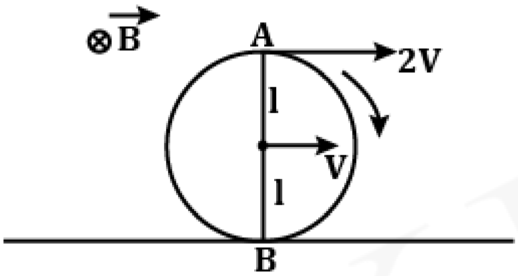
$v_A = 2v$

Also, velocity of point B is,

$v_B = 0$

∴ Angular velocity of rod AB about point B is,

$\omega = \frac{v_A}{r_A} = \frac{2v}{2l} = \frac{v}{l}$



∴ Potential difference between points A and B is,

$V_A - V_B = \frac{B\omega L^2}{2}$

$V_A - V_B = \frac{B \times \frac{v}{l} \times (2l)^2}{2} = \frac{Bv \times 4l}{2}$

$\therefore V_A - V_B = 2Bvl$

Hence, option (B) is the correct answer.

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8. Assertion : A bar magnet is dropped into a long vertical copper tube. Even taking air resistance as negligible, the magnet attains a constant terminal velocity. If the tube is heated, the terminal velocity gets increased.
Reason : The terminal velocity depends on the eddy current produced in the bar magnet.

- ✔ **A.** Both the assertion and reason are true and the reason is the correct explanation of the assertion.
- ✖ **B.** Both the assertion and reason are true, but reason is not the correct explanation of the assertion
- ✖ **C.** The assertion is true but reason is false.
- ✖ **D.** The assertion and reason both are false.

When the magnet is dropped down through a long copper tube, the magnetic flux linked with the copper tube changes continuously. Due to this change in flux linked with the copper tube, there is induction of an eddy current.

According to Lenz's law, the eddy current generated opposes the change in the magnetic field linked with the copper tube and hence, applies an upward retardation force on the magnet.The other force acting on the magnet is its own weight in the downward direction.

Since the magnet is in the free fall and moves under the influence of the acceleration due to gravity, the velocity of the magnet increases in the downward direction and the magnet is in the accelerated motion. But as the magnet moves downward with increasing velocity, the eddy current generated opposes the change in magnetic flux linked with the copper tube largely.

Hence, the retarding force by the eddy currents increases to such an extent that at a point the weight of the magnet in the downward direction becomes equal to the upward retarding force. Therefore, the velocity of magnet becomes constant.

When the tube is heated, its resistance gets increased due to which eddy currents produced in copper tube becomes weak. Hence, the opposing force also gets reduced and the terminal velocity of the magnet gets increased.

Hence, both assertion and reason are correct and reason is a correct explanation of the assertion.

Thus, (A) is the correct answer.

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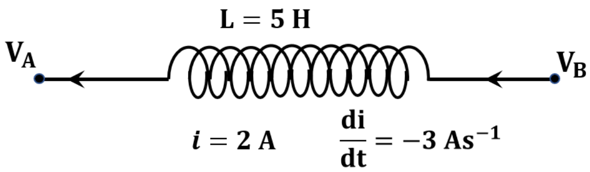
9. Find $V_A - V_B$ in the given figure ?

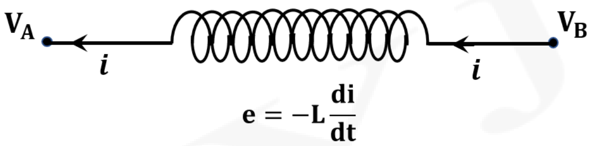


A. -15 V

B. 10 V

C. 30 V

D. 15 V



Using KVL,

$$V_B - L\frac{di}{dt} - V_A = 0$$

$$V_B - [5(-3)] - V_A = 0$$

$$V_B - V_A = -15 \text{ V}$$

$$V_A - V_B = 15 \text{ V}$$

Hence, (D) is the correct answer.

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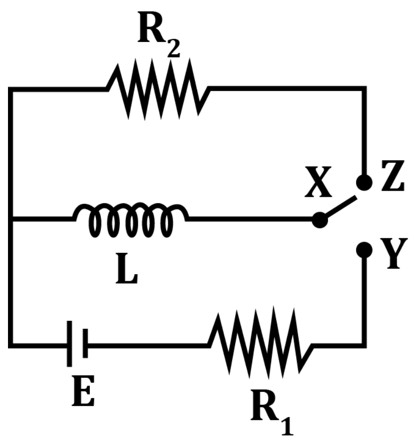
10. In the ideal inductor circuit shown, X is joined to Y for a long time, and then X is joined to Z. The total heat produced in R_2 is:



A. $\frac{LE^2}{2R_1^2}$

B. $\frac{LE^2}{2R_2^2}$

C. $\frac{LE^2}{2R_1R_2}$

D. $\frac{LE^2R_2}{2R_1^3}$

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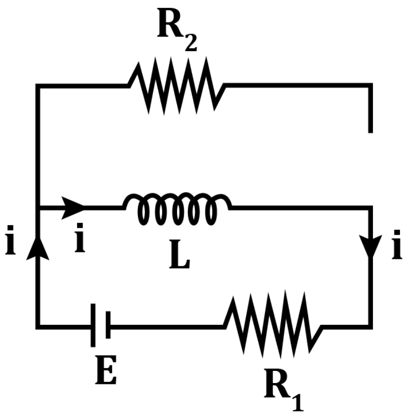
When the switch X is connected to the Y, the current flowing in the circuit is,

$$i = \frac{E}{R_1}$$



$\therefore$ Energy stored in the inductor is,

$$E_i = \frac{1}{2}Li^2$$

$$= \frac{1}{2}L \times \left(\frac{E}{R_1}\right)^2 = \frac{LE^2}{2R_1^2}$$

When the switch X is connected to Z the current and the energy stored in the inductor will decay through resistance R_2.

Therefore, the total energy stored in the inductor will be converted into the heat energy produced in R_2.

Hence, (A) is the correct answer.

Note:
The total heat produced in the circuit is independent of the resistance R_2.

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11. Two coils X and Y are placed in a circuit such that when the current changes by $2\ \mathrm{A}$ in coil X the magnetic flux changes by $0.4\ \mathrm{Wb}$ in Y. The value of mutual inductance of the coils is-

- ✔ **A.** $0.2\ \mathrm{H}$
- ✖ **B.** $5\ \mathrm{H}$
- ✖ **C.** $0.8\ \mathrm{H}$
- ✖ **D.** $4\ \mathrm{H}$

From the principle of mutual inductance,

$$\phi_2 = Mi_1 \quad \text{(or)}$$

$$\Delta\phi_2 = M(\Delta i_1)$$

$$\Rightarrow \quad M = \frac{\Delta\phi_2}{\Delta i_1} \ldots . (1)$$

Where, $\phi_2 = \text{Flux through the second coil}$
$i_1 = \text{Current in the first coil}$
$M = \text{Co-efficient of mutual inductance}$

Here, $\Delta i_1 = 2\ \mathrm{A}\ ; \ \ \Delta\phi_2 = 0.4\ \mathrm{Wb}$

Putting this values in (1) we get,

$$M = \frac{\Delta\phi_2}{\Delta i_1} = \frac{0.4}{2} = 0.2\ \mathrm{H}$$

Hence, (A) is the correct answer.

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12. Assertion (A): Self-inductance is called the inertia of electricity.

Reason (R): Self-inductance is the phenomenon, according to which "an opposing induced e.m.f. is produced in a coil as a result of change in current (or) magnetic flux linked in the coil".

- ✔ **A.** Both (A) and (R) are true, and (R) is the correct explanation of (A)
- ✖ **B.** Both (A) and (R) are true, but (R) is not the correct explanation of (A)
- ✖ **C.** (A) is true but (R) is false
- ✖ **D.** (A) is false but (R) is true

A massive body opposes the change in its state of uniform motion (or) rest due to inertia.

Similarly, self-induction of a coil is the property by virtue of which it tends to maintain the magnetic flux linked with it and opposes any change in the flux by inducing current in it.

This property of a coil is analogous to mechanical inertia. That is why self-induction is called the inertia of electricity.

Hence, (A) is the correct answer.

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13. Assertion (A): When two coils are wound on each other, the mutual induction between the coils in maximum.

Reason (R): Mutual induction does not depend on the orientation of the coils.

- **A.** Both (A) and (R) are true, and (R) is the correct explanation of (A)
- **B.** Both (A) and (R) are true, but (R) is not the correct explanation of (A)
- **C.** (A) is true but (R) is false ✔
- **D.** (A) is false but (R) is true

As we know, the coefficient of mutual inductance is,

$$M = \frac{\left(\frac{-d\phi_2}{dt}\right)}{\left(\frac{-di_1}{dt}\right)} = \frac{e_2}{\left(\frac{-di_1}{dt}\right)}$$

When coils are mounted one over other the flux linkage is maximum, so mutual inductance will be maximum.
Hence, the assertion is correct.

Flux linkage will definitely depend upon the orientation of the coils. So the reason is false.

Hence, (C) is the correct answer.

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14. Assertion (A): The quantity $\left(\frac{L}{R}\right)$ possesses dimension of time.

Reason (R): To reduce the rate of increase of current through a solenoid, we should increase the time constant $\left(\frac{L}{R}\right)$.

- ✗ **A.** Both (A) and (R) are true, and (R) is the correct explanation of (A)
- ✓ **B.** Both (A) and (R) are true, but (R) is not the correct explanation of (A)
- ✗ **C.** (A) is true but (R) is false
- ✗ **D.** (A) is false but (R) is true

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Let us take a formula from LR circuit as,

$$I = I_0\left[1 - e^{-\frac{t}{\left(\frac{L}{R}\right)}}\right]$$

Since $\frac{t}{\left(\frac{L}{R}\right)}$ must be dimensionless

$\Rightarrow \frac{L}{R}$ must have dimension of time.

$\Rightarrow$ Assertion is true.

We know,

$$I = \frac{\mathcal{E}}{R}\left(1 - e^{-\left(\frac{t}{\tau}\right)}\right) \quad \left[\because \ \tau = \left(\frac{L}{R}\right) = \text{Time constant}\right]$$

$$\frac{dI}{dt} = \frac{\mathcal{E}}{R}\left(\frac{1}{\tau}e^{\left(\frac{-t}{\tau}\right)}\right)$$

$$\frac{dI}{dt} \propto \frac{1}{\tau}$$

$\Rightarrow$ Reason is also correct but it does not explain the assertion.

Hence, (B) is the correct answer.

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15. Assertion (A): The induced e.m.f. and current will be same in two identical loops of copper and aluminium when rotated with same speed in the same magnetic field.

Reason (R): Induced e.m.f. is proportional to rate of change of magnetic field while induced current depends on resistance of wire.

- **A.** Both (A) and (R) are true, and (R) is the correct explanation of (A)
- **B.** Both (A) and (R) are true, but (R) is not the correct explanation of (A)
- **C.** (A) is true but (R) is false
- **D.** (A) is false but (R) is true ✔

As we know, induced e.m.f. $e = -\frac{d\phi}{dt}$

Flux linkage with a coil is independent of the material. So emf will be same as the loops are identical in shape.

But induced current

$$i_{ind} = \frac{\left(-\frac{d\phi}{dt}\right)}{R} = \frac{e}{R}$$

And $R = \frac{\rho l}{A}$ [it depends on the property of the material.]

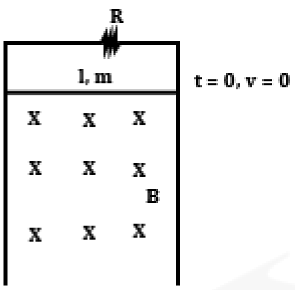
Hence, induced current will depend upon the material because Resistivity (ρ) is material dependent.

Hence, (D) is the correct answer.

16. Comprehension:

A conducting rod of mass m and length l is released from rest on smooth metallic rails placed in vertical plane in a uniform horizontal magnetic field (B) as shown in figure.

When rod falls, it would cut magnetic field lines and motional emf will be induced. Velocity and acceleration of rod will change with time and after a long time rod will achieve a maximum velocity called as terminal velocity.

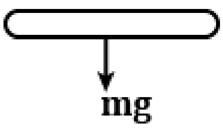


Answer the following question based on above discussion.

(i) The initial acceleration ($t=0)$ of the rod will be

- ✔ **A.** g downwards
- ✖ **B.** Less than g downwards
- ✖ **C.** More than g downwards
- ✖ **D.** Less than g upwards

From FBD of the rod we get,



At $t=0$, the only force acting on the rod is mg downwards,

$\because$ At $t=0$, no current flows through the rod, we can say that magnetic force is zero.

$\therefore a=\frac{F}{m}=\frac{mg}{m}=g$ downwards

Hence, (A) is the correct answer.

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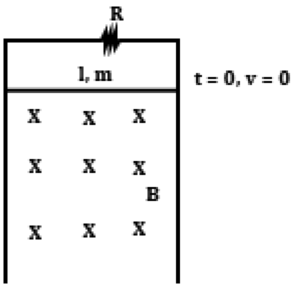
17. Comprehension:

A conducting rod of mass m and length l is released from rest on a smooth metallic rails placed in vertical plane in a uniform horizontal magnetic field (B) as shown in the figure. When rod falls, it would cut magnetic field lines and motional emf will be induced. Velocity and acceleration of rod will change with time and after a long time rod will achieve a maximum velocity named as terminal velocity.



Answer the following question based on above discussion.

(ii) As the rod falls down, (well before achieving terminal velocity)
Which of the given options is correct?

A. Acceleration increases, velocity increases

B. Acceleration decreases, velocity increases (✓ correct)

C. Acceleration remains constant, velocity decreases

D. Acceleration decreases, velocity constant

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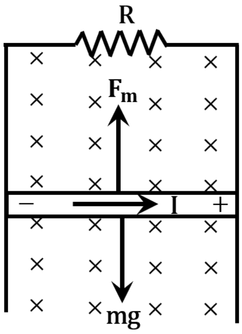
At any instant $t > 0$,



Acceleration of the rod will be,

$$a = \frac{mg - F_{mag}}{m} = g - \frac{F_{mag}}{m}$$

So $a < g$, but acceleration does not change its direction.

Thus, velocity will increase.

Hence, (B) is the correct answer.

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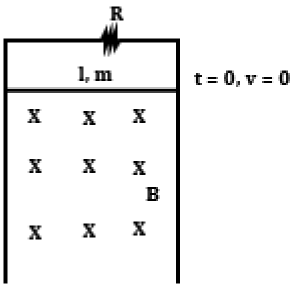
18. Comprehension:

A conducting rod of mass m and length l is released from rest on a smooth metallic rails placed in vertical plane in a uniform horizontal magnetic field (B) as shown in the figure. When rod falls, it would cut magnetic field lines and motional emf will be induced. Velocity and acceleration of rod will change with time and after a long time rod will achieve a maximum velocity named as terminal velocity.



Answer the following question based on above discussion.

(iii) The velocity of the rod when it has achieved its terminal value.

A. $\frac{mgR}{Bl}$

B. $\frac{mgR}{Bl^2}$

C. $\frac{mgR}{B^2l^2}$ ✔

D. $\frac{mgR}{2B^2l^2}$

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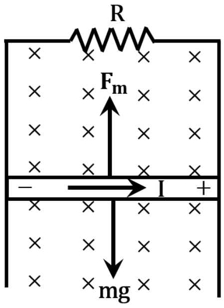
At terminal velocity (v_t), acceleration of the rod ceases i.e.,$a_{rod} = 0$



$$\Rightarrow \quad mg = F_m$$

$$\Rightarrow \quad mg = ilB \quad \left[\because\ i = \frac{Blv_t}{R}\right]$$

$$\Rightarrow \quad mg = \frac{B^2 l^2 v_t}{R}$$

$$\Rightarrow v_t = \frac{mgR}{B^2 l^2}$$

Hence, (C) is the correct answer.

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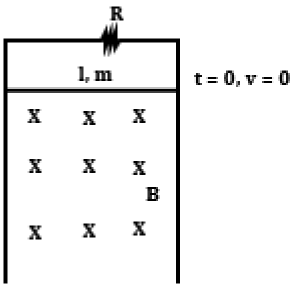
19. Comprehension:

A conducting rod of mass m and length l is released from rest on a smooth metallic rails placed in vertical plane in a uniform horizontal magnetic field (B) as shown in the figure. When rod falls, it would cut magnetic field lines and motional emf will be induced. Velocity and acceleration of rod will change with time and after a long time rod will achieve a maximum velocity named as terminal velocity.



Answer the following question based on above discussion.

(iv) Which of the options is true for the above passage ?

- ✗ **A.** When the rod has achieved terminal velocity, current in the resistor is zero.
- ✗ **B.** Current in the resister first increases, then decrease.
- ✓ **C.** The acceleration - velocity graph of the motion of the rod will be a straight line.
- ✗ **D.** The velocity-time graph of rod will be a parabola.

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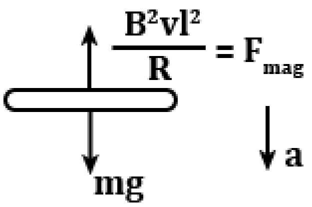
(i). When the rod achieves terminal velocity, motional emf will be constant, so current in the resistor will be non-zero and constant.
$\Rightarrow$ Option (A) is incorrect.

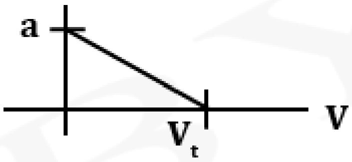
(ii). Velocity of rod continuously increase and emf (Bvl) will also increase till terminal velocity is achieved, after that it will become constant
$\Rightarrow$ Option (B) is incorrect.

(iii). Acceleration-velocity graph of the rod is,

At any instant , $t > 0$, from the FBD of the rod, we get,



$$mg - \frac{B^2l^2v}{R} = ma \ldots\ldots (1) \quad [\text{this is similar to the equation of straight line}]$$



$\Rightarrow$ Option (C) is correct.

(iv). From (1) discussed above,

$$\frac{dv}{dt} = g - \frac{B^2l^2v}{mR}$$

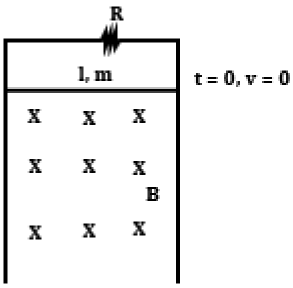
$$\Rightarrow \int_0^v \frac{dv}{\left(g - \frac{B^2l^2v}{mR}\right)} = \int_0^t dt$$

The above equation converts to exponential form.
$\Rightarrow$ Option (D) is incorrect.

Hence, (C) is the correct answer.

20. Comprehension:

A conducting rod of mass m and length l is released from rest on a smooth metallic rails placed in vertical plane in a uniform horizontal magnetic field (B) as shown in the figure. When rod falls, it would cut magnetic field lines and motional emf will be induced. Velocity and acceleration of rod will change with time and after a long time rod will achieve a maximum velocity named as terminal velocity.



Answer the following question based on above discussion.

(v) Thermal power in the resistor is plotted on y-axis, against speed on the x-axis, the graph will be a-

- ✗ **A.** Straight line
- ✓ **B.** Parabola
- ✗ **C.** Exponential curve
- ✗ **D.** None of the above

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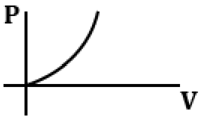
The induced emf in the rod, $\mathcal{E} = Bvl$

The induced currant through the resistor is,

$$i = \frac{Bvl}{R}$$

Thermal power, $P = i^2R = \left(\frac{B^2v^2l^2}{R^2}\right)R$

$$\Rightarrow P = \frac{B^2v^2l^2}{R}$$



Hence, (B) is the correct answer.