PHYS 2212 Problem-Solving Studio 10

Apr 11–14

Safety Through Magnetism

Your Co-Op job involves the development of a system to safely lower large loads down ramps. The idea is to use a magnetic system to control the downward speed of the load. The system consists of parallel conducting rails embedded in the ramp, and a moveable conducting bar that slides down the ramp, while in contact with the rails. A fixed conducting bar at the bottom of the ramp connects the two rails, forming a closed rectangular circuit. The bar slides down the rails through a vertical uniform magnetic field, at a constant velocity even when friction between the bar and the rails is negligible. You need to know the constant speed of the sliding bar, as a function of its mass and length, the strength of the magnetic field, the angle of the ramp from the horizontal, and the electrical resistance of the bar.

SOLUTION

Instructions:

Construct a visual representation of the situation described, with all physical quantities represented by symbolic variables. Identify the concepts that will be needed to answer the question posed, as well as any simplifying assumptions that you will use. Outline a plan (that is, a series of analytical steps) that you will use solve the problem, and then follow those steps to solve the problem.

You may work as a group to complete this exercise, but each student is expected to submit an individual solution.

Assumptions – no friction
– rails have no resistance
(all R is in moving bar)

Formulation/Outline of solution

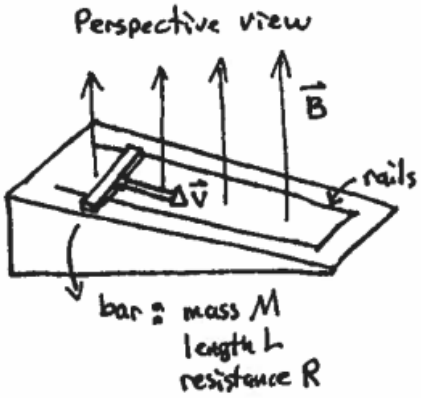
① Motional emf: mag force on moving electrons in bar = $q\vec{v}\times\vec{B}$. This forces neg charges to left side of bar, and pos charges to right

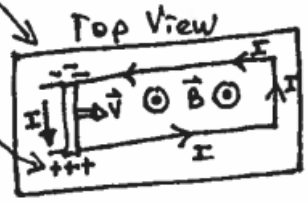
② Rails provide loop for a ccw current. In bar, this results in left-to-right current in bar (as viewed looking in direction of motion)

③ Magnetic force on bar as a whole, due to current flowing through it is $\vec{F} = I\vec{L}\times\vec{B}$. RHR tells us this force is horizontal and "backward"

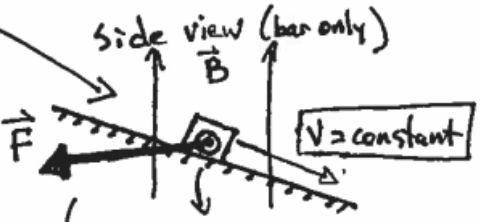
④ If bar is moving at constant speed, it must be in equilibrium $\Sigma\vec{F}=0$

Hence: determine speed v at which the moving bar is in equilibrium

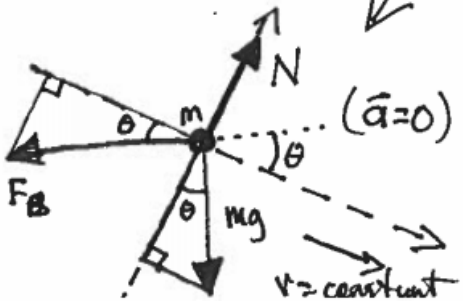




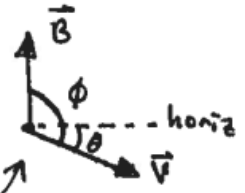
note that $(e\vec{v})$ points upslope!



magnetic force on bar (due to current I) is $\vec{F} = I\vec{L}\times\vec{B}$ = horizontal/back



① Motional emf is found by first determining the induced $\vec{E}$-field, based on the requirement that $|\vec{F}_B| = |\vec{F}_e|$, charges in equilibrium



$\vec{F}_B = q\vec{v}\times\vec{B} = (-e)\vec{v}\times\vec{B}$

$\rightarrow |\vec{F}_B| = e|\vec{v}||\vec{B}|\sin\phi$, where $\phi = 90° + \theta$

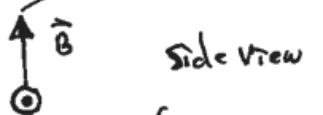
$|\vec{F}_e| = |\vec{F}_B| = evB\sin(90°+\theta)$

$e\vec{E}_{ind} = evB\cos\theta \rightarrow \boxed{E_{ind} = vB\cos\theta}$ Field

Then $\Delta V_{ind} = \mathcal{E}_{motional} = E_{ind}\cdot L \rightarrow \boxed{\mathcal{E}_{ind} = vBL\cos\theta}$ emf

② loop rule for circuit

$+\mathcal{E}_{ind} - I_{ind}R = 0 \rightarrow I_{ind} = \frac{\mathcal{E}_{ind}}{R} = \frac{vBL\cos\theta}{R}$



③ Magnetic force on bar is $\vec{F}_{bar} = I\vec{L}\times\vec{B}$

$= \frac{vB^2L^2\cos\theta}{R}$, horizontal to left

④ 2nd Law analysis

$\Sigma\vec{F}_y = 0 = +N - F_B\sin\theta - Mg\cos\theta = 0$

$\boxed{\Sigma\vec{F}_x = 0 = +mg\sin\theta - F_B\cos\theta = 0} \rightarrow F_B = mg\tan\theta$

$\frac{vB^2L^2\cos\theta}{R} = mg\tan\theta$

$$\boxed{V = \frac{mgR\sec\theta\tan\theta}{B^2L^2}}$$