# Date Question Set 1a
# Investigating Magnetic Braking

Team Decoherence

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## 1 Introduction

When a piece of metal is place in time-dependent magnetic field or forced to move in a time-independent but non-uniform magnetic field, currents are generated in the metal.

**Q1)** Explain why currents are generated in both the situations separately. [2]

These currents cause joule heating in the metal and since energy is being dissipated, a magnetic drag force is induced to slow down the metal. This phenomenon is called magnetic breaking.

**Q2)** In the following scenario, provide diagram(s) of field lines and forces to describe the mechanism of magnetic braking - magnet falling through a long vertical metallic pipe [2]

## 2 Magnet rolling on an inclined plane

When a magnet moves near a non-magnetic conductor such as copper and aluminum it experiences a dissipative force called magnetic braking force. In this experiment we will investigate the nature of this force. The magnetic braking force depends on:

1. the strength of the magnet, determined by its magnetic moment ($\mu$);
2. the conductivity of the conductor ($\sigma C$);
3. the size and geometry of both magnet and the conductor;
4. the distance between the magnet and conducting surface ($d$); and
5. the velocity of the magnet ($v$) relative to the conductor.

In this experiment we will investigate the magnetic braking force dependencies on the velocity ($v$) and the conductor-magnet distance ($d$). This force can be written empirically as:

$$F_{MB} = -k_0 d^p v^n$$

where $k_0$ is an arbitrary constant that depends on $\mu$, $\sigma C$ and geometry of the conductor and magnet which is fixed in this experiment. $d$ is the distance between the center of magnet to the conductor surface. $v$ is the velocity of the magnet. $p$ and $n$ are the power factors to be determined in this experiment.

# 3 Experiment Setup

## 3.1 Apparatus

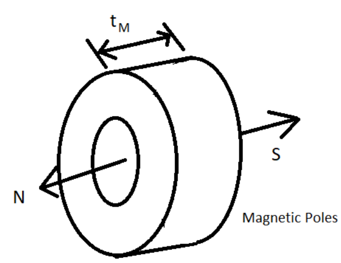


Figure 1:

1. Doughnut-shaped Neodymium Iron Boron magnet. Thickness: $t_M = (6.3 \pm 0.1)$ mm
2. Outer diameter: $d_M = (25.4 \pm 0.1)$ mm
3. Aluminum bar (2 pieces)
4. Acrylic plate for the inclined plane (with adjustable height) with a linear track for the magnet to roll

The poles are on the flat faces as shown in Fig 1:

## 3.2 Additional Information

Local gravitational acceleration: $g = 9.8$ m/s2 Mass of the magnet: $m = (21.5 \pm 0.5)$ g North-South direction is indicated on the table. You can read the operation manual of the stopwatch This problem is divided into two sections:

1. Setup and introduction
2. Investigation of the magnetic braking force

Remarks: Make sure that the plane is clean before your experiment

# 4 Questions

## 4.1 Setup and Forces

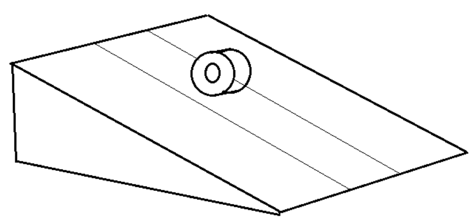

Figure 2: Setup without Al bars

The magnet is rolling down along the track as shown. A reasonably small inclination is chosen angle so that it does not roll too fast.

1. As the magnet is very strong, it may experience significant torque due to interaction with earth's magnetic field. It will twist the magnet as it rolls down and may cause significant friction with the track. What will you do to minimize this torque? Explain it using diagram(s).[1.5]

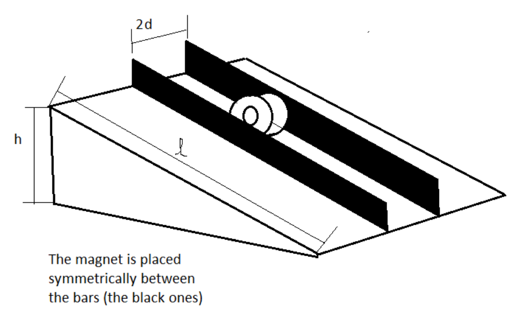


Figure 3: A complete setup with Al bars

The two aluminum bars are placed as shown in Figure 3 with distance approximately $d = 5$mm.

Again, the magnet is released and let roll. You should observe that the magnet would roll down much slower compared to the previous observation due to magnetic braking force.

1. Provide diagram(s) of field lines and forces to describe the mechanism of and variation in speed of the magnet[1.5]

### 4.2 Investing the Force

The experimental setup remains the same as shown in Figure 3 with the same magnet-conductor distance approximately $d = 5$ mm (about 2 mm gap between magnet and conductor on each side).

1. Keeping the distance $d$ fixed, $h$ is varied and the time to cover a distance of 250mm on the incline is measured. Assume that in this 250mm, the magnet was moving with its terminal velocity. $l = 425$mm. Determine the exponent n of the speed dependence factor in Equation 1. Provide appropriate graph to explain your result. Refer to DATA SET 1 for the required data. Derive any relation needed. Show the derivation clearly.[2]

A fixed and reasonably small inclination angle is chosen. $d$ is varied, rest other parameters are kept constant.

1. Investigate the dependence of the magnetic braking force on conductor-magnet distance ($d$) - Determine the exponent p of the distance dependence factor in Equation 1. Provide appropriate graph to explain your result. Refer to DATA SET 2 for the required data. Here also, a distance of 250mm is considered for the time readings.[1]