The Relationship between Electrical Conductivity and Magnetically Dampened Motion

A magnet falling through a metal tube will reach terminal velocity due to induced eddy currents.
The time taken to reach terminal velocity depends on the conductivity of the metal tube.

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Research Question:

Does the conductivity of different metal tubes (Aluminium, Copper and Brass) determine the time a falling magnet takes to reach terminal velocity?

Background:

Faraday's Law of Induction:

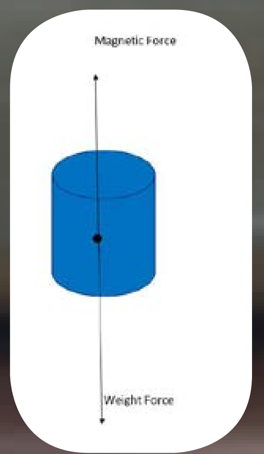
The slow fall of a magnet through a metal tube is a demonstration of Lenz's Law. The changing magnetic flux from the falling magnet induces an emf in the metal tube.

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

where ε represents the voltage, Φ_B represents the magnetic flux and t represents time.

Eddy currents:

Eddy currents are formed as a result of the emf and produce their own magnetic field which opposes the initial field. This causes dampened motion, as the two fields oppose each other, balancing the force of gravity on the magnet.



When the magnetic force equals the gravitational force the magnet reaches terminal velocity. The terminal velocity of the magnet will be measured for varying length tubes of aluminium, copper and brass.

It is expected that metals with greater electrical conductivities will have greater eddy currents formed, and the magnet will reach terminal velocity faster.

Methodology:

1. The apparatus was assembled as shown in Figure 1, with the metal tube clamped by the retort stand and the plastic tub positioned below the tube. The experiment was undertaken in front of a whiteboard for a clear background.
2. The video camera was attached to the tripod and was set at a quality of 1080p and a frame rate of 30fps.
3. The metal type, tube length and trial number was noted on the whiteboard with the whiteboard marker and video recording was started.
4. The neodymium magnet was dropped into the tube and once it landed in the plastic tub beneath video recording was stopped.
5. The process was repeated until 5 trials had been recorded for each tube.

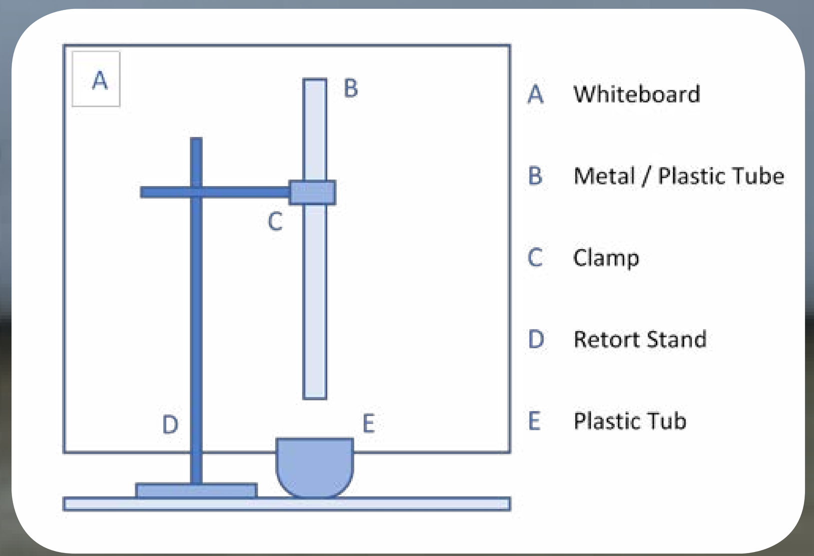


Figure 1. Schematic of apparatus setup

Raw Data:

Tube Material	Lengths (±0.001m)	Time to traverse the tube (±0.03s)					Average Times (s)	
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean	Uncertainty
Aluminium 1	0.200	0.8000	0.8333	0.8333	0.7667	0.8000	0.8067	± 0.0400
Aluminium 2	0.400	1.7000	1.5667	1.6333	1.6667	1.6000	1.6333	± 0.0667
Aluminium 3	0.600	2.4333	2.3667	2.4000	2.3667	2.4333	2.4000	± 0.0333
Aluminium 4	0.800	3.2667	3.5333	3.4333	3.1333	3.1667	3.3067	± 0.2267
Aluminium 5	1.000	4.1667	4.0333	4.0667	4.1333	3.9667	4.0733	± 0.1067
Aluminium 6	2.005	8.3333	8.1000	8.3000	8.2000	8.1667	8.2200	± 0.1200

Table 1. Raw data from the aluminium tube lengths

Figure 2. Photograph of the experimental setup

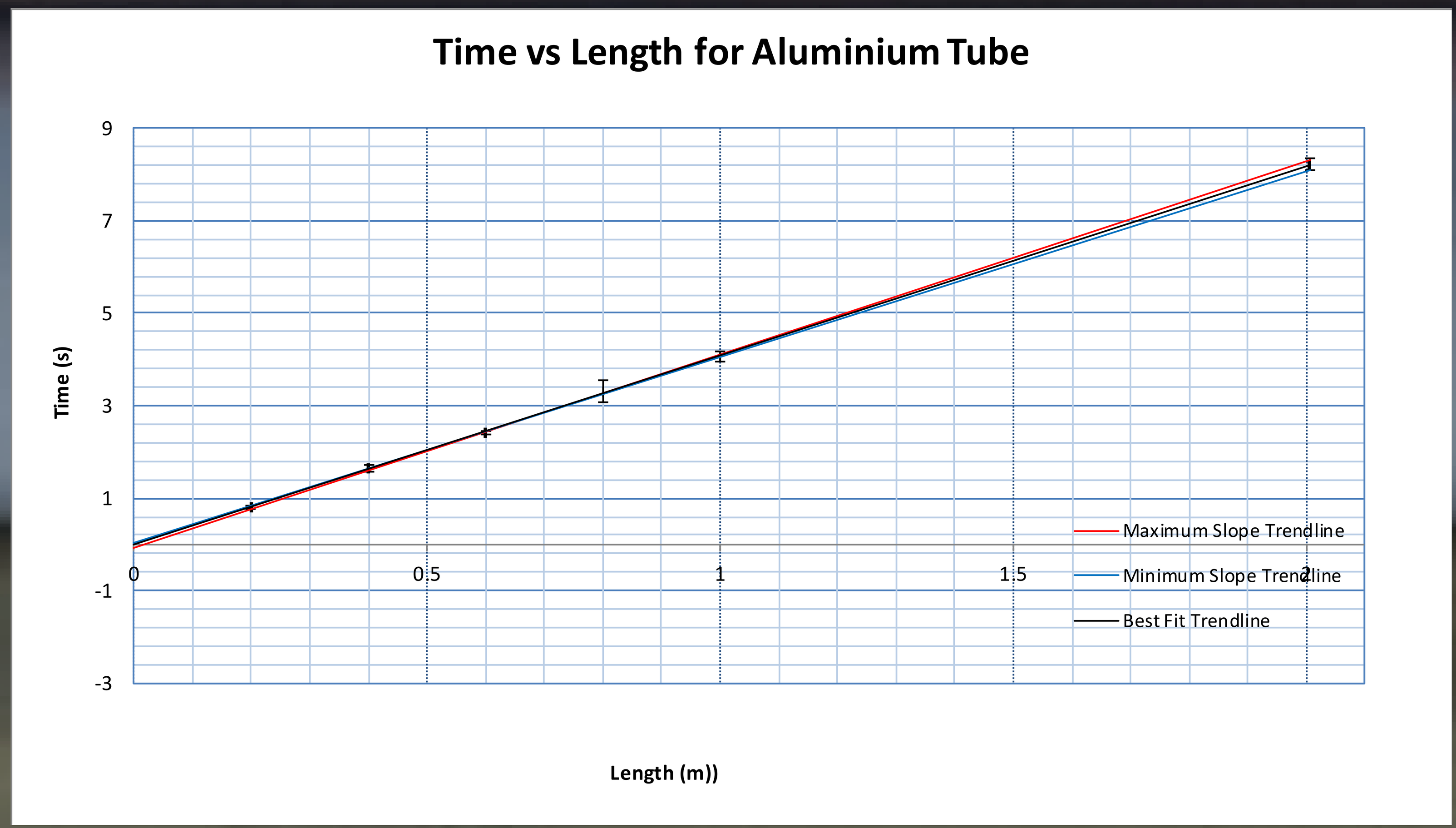


Figure 3. Graph of Aluminium tube times used to calculate terminal velocity of the magnet

Analysis and Evaluation:

The terminal velocity of the magnet was determined for each metal type using a graph like the one shown in Figure 3. The maximum and minimum slopes were used to determine the uncertainty. The terminal velocities were tabulated along with the conductivities of the metals.

Tube Material	Conductivity (S/m)	Terminal Velocity (m/s)	
		Mean	Uncertainty
Aluminium	37700000	0.2437	± 0.0169
Brass	15400000	0.4852	± 0.0689
Copper	59500000	0.2408	± 0.0403

Table 2. Processed data for three metals. Terminal velocity calculated from 5 trials of 6 lengths for each metal.

Although it is not possible to establish a trend with only three metal types it appears that conductivity is inversely proportional to terminal velocity.

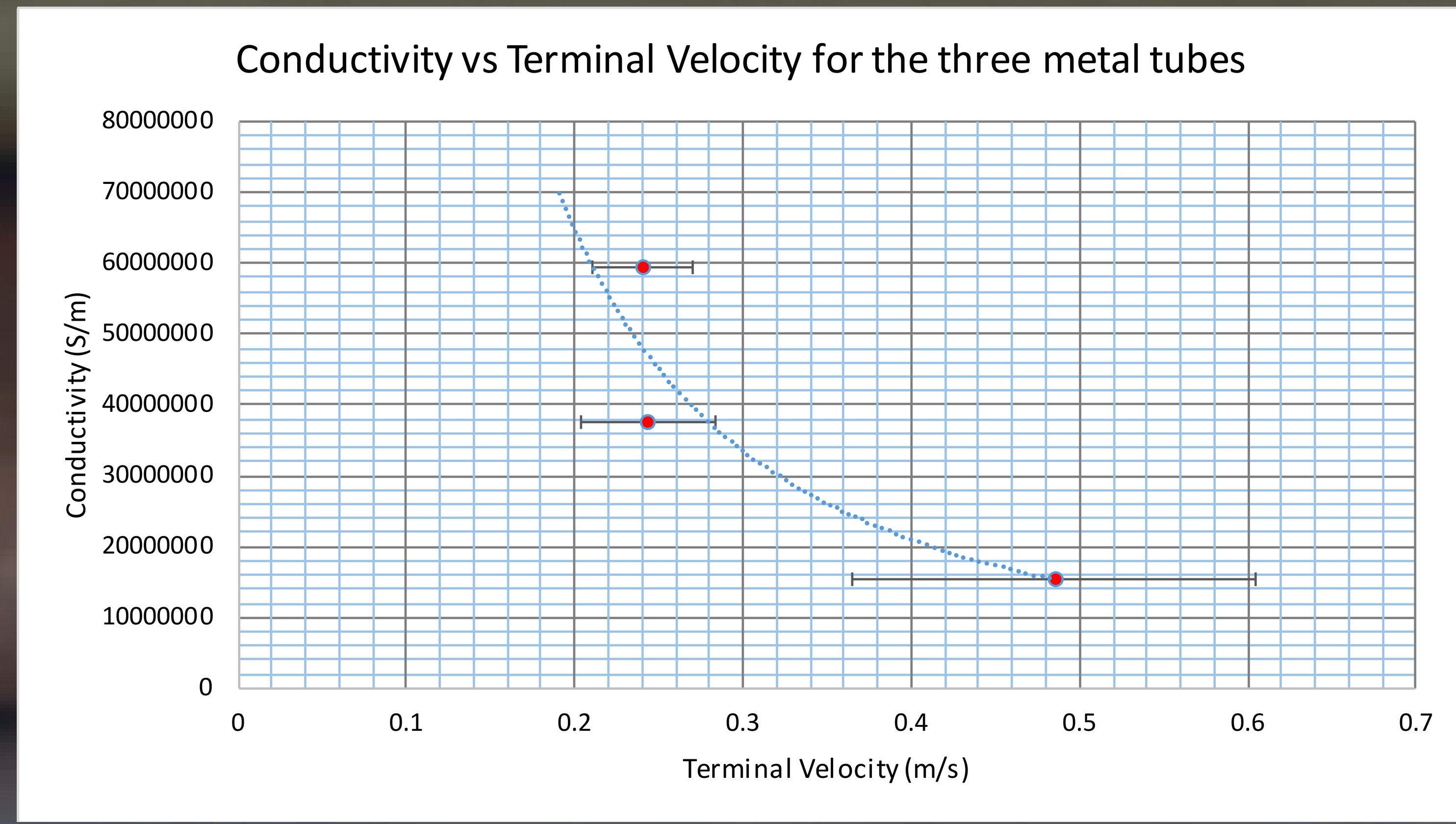


Figure 4. Conductivity and terminal velocity for the three metal tubes.

Sources of error in the experiment arise from random errors associated with dropping and timing the magnet's fall through the tube. These errors were minimised by using a video camera to record the motion. By carefully reviewing the film frame by frame the time interval was accurately determined. Multiple trials ensured the results were reliable.

Conclusion:

The experiment was successful in identifying the metal with the maximum dampening effect to be copper, and the hypothesis was proven to be correct as the terminal velocity was inversely proportional to conductivity.

Applications:

Eddy currents have many practical applications as the unique properties of the currents allow for a very smooth dampening of motion. Some examples where eddy currents could be used are in the safe braking of high speed trains or in emergency stopping for dangerous machinery. Knowledge of the relationship between magnetic braking and conductivity would allow for the use of different metals in different applications enabling optimisation.