Background/Research:

Lenz Law: Lenz's Law was discovered by Heinrich Lenz in 1834 which describes electromagnetic induction, where a changing magnetic field induces a current in a nearby conductor. This current will always flow in a direction that opposes the change in magnetic flux that produced it. When the magnetic flux changes continuously, circulating currents known as eddy currents are generated. Due to the electrical resistance of the conductor, these currents produce heat. This process uses the law of conservation of energy, as the current resists changes in magnetic flux. Modern applications of Lenz's Law include induction heating and technologies designed to harness renewable energy.

Implementing Lenz's Law in practice presents several challenges. A common misunderstanding associated with the law is the negative sign in Faraday's equation, $EMF = -d\Phi/dt$. It indicates that the induced current opposes the change in magnetic flux, which is critical for maintaining energy balance. Interpreting this negative is essential, as it ensures energy is conserved during opposing flux changes (not violating the law of conservation).

Despite these challenges, Lenz's Law has been used as the foundation for the development of generators, transformers, induction heating systems, and magnetic braking technologies. However, these systems have not yet reached their full efficiency potential. Some question whether the negative sign in the equation contradicts the law of conservation of energy; it does not. The negative simply accounts for the opposing magnetic flux. Changes in conductor properties, such as increased surface area, can enable larger eddy currents to form, resulting in greater heat generation and enhanced system efficiency. The negative also accounts for the fact over time it is inevitable the magnet will heat up which causes its polarity to weaken.

Eddy currents: Eddy currents are electrical currents that form within conductors when they are exposed to a changing magnetic field.

The first observations of these currents were made by François Arago in 1824, when he found that conductive materials could become magnetized through motion and magnetic interaction (Argos Rotation Experiment 1824). These observations were later explained by Michael Faraday in 1831 through Faraday's Law of Induction, which states that when the magnetic field around a conductor changes, voltage is induced in said conductor, then if the conductor provides a closed path, this voltage causes an electrical current to flow (eddy currents), which circle through the conductor.

In 1834, Heinrich Lenz introduced Lenz's Law, which explains the direction of these currents. It states that the induced current will flow in a direction that opposes the change in magnetic field that produced it. Essentially the current will flow in opposite to the change in magnetic field. Because of this, eddy currents create a secondary magnetic field that resists the original magnetic change (reason for the negative in Faraday's equation).

When a conductor moves/surrounds a non-uniform magnetic field, electromotive forces (EMFs) are generated within loops of the material. These EMFs cause the eddy currents to dissipate energy as heat, further proving Faraday's and Lenz's Law. This heating effect is a direct result of the loss of electrical energy within the conductor.

Joule's Law explains the relationship between work and heat energy within a system. It states that the amount of work done on or within a system directly correlates to the heat added to that system. The law was established by James Prescott Joule in 1840 through a series of experiments studying energy conversion.

One of Joule's main experiments involved stirring water using paddles connected to falling weights. As the weights dropped, they turned the paddles, causing them to stir the water and increase its overall temperature. Joule measured the temperature rise and compared it to the amount of mechanical work done by the falling weights. Using the heat equation ($Q=mc\Delta T$) he was able to measure the heat produced.

Through this experiment, Joule demonstrated that mechanical energy could be converted into thermal energy. This discovery helped confirm the principle of energy conservation, showing that energy is not created or destroyed, but instead transformed from one form to another.

Resistive Heaters Fundamentals:

Resistive heaters work by passing an electric current through a material that is conductive of electricity. The resistance causes the electrical energy into thermal, which then warms the surrounding area through conduction, convection, or radiation.

The first practical resistive heater was created by **Albert Leroy Marsh in 1905**, when he developed a high-resistance alloy called nichrome that could safely generate heat without melting (Still used till this day).

Copper v Aluminum conductivity:

When picking a conductor for the heater we must look at the conductivity. Compared to aluminium copper has a much lower electrical volume resistivity sitting at 0.017241 (Ω x mm2)/m where as aluminium has 0.0282 (Ω x mm2)/m which may seem like a very small comparison but each digit matters. The more resistive the material is, the less energy it will be able to produce and our experiment will test and prove efficiency. Copper would also be the more suitable material as its thermal expansion is much lower. Thermal expansion is also a key plate as stated in Faraday's equation (insert equations) the negative there is to account for the loss of magnetic flux caused by expansion of the copper. Thus for this experiment, copper will be most suited for our desired outcome.

When building the heater a main component we have to look out for is whether or not all the magnets have the same pole facing outward. If the poles are fiz it will affect the direction of the induced current which would affect the inertia. Inertia is the natural tendency of an object to resist the opposing motion.. The goal of this heater is convert kinetic energy (energy of movement) and convert it into thermal energy, if the induced currents were flowing in opposite directions it would counteract each other, causing them to essentially "misfire" and us losing the electronic dissipation in the process.

Manipulated variable:

- Type of heater

Responding variable:

- Temperature raised above SATP
- Energy output

Controlled variable:

- Distance of thermometer from heater
    - thermometer
- Energy input
- Space of room
- Max time will be 1 hour
- Type of magnets

Procedure:

Materials

- 6V motor, MONTOY Build-It-Yourself kit, Stripper and wire cutter, Clay (polymer or air-dry), 3 × 3 cm neodymium magnets (x2), 1 cm circular neodymium magnets (x8), 2.5 cm screws (various), Drill and drill bits, Cardboard, Jenga blocks 2.1 × 7.6 cm (x6), Foam, Super glue, Baseboard: 31.7 × 10.3 cm, thickness 1.3 cm, copper wire: 12 ft, Hot glue gun

Base Construction

1. Place 2 Jenga blocks horizontally toward the center of the baseboard with a 4.5 cm gap between them
2. Drill four pilot holes from the bottom of the baseboard into the Jenga blocks (2 per block, evenly spaced)
3. Screw in 4 screws from the bottom, ensuring they are flush
4. Stack 2 more Jenga blocks on top of the original stands, side by side

Motor Mount

5. Place the motor on top of the two horizontal Jenga blocks
6. Use 2 D09 pieces from the MONTOY kit to secure the motor: bend across the motor body and mark where they meet the side of the Jenga blocks
7. Drill pilot holes and secure the motor with the D09 pieces, sandwiching the motor
8. Fill any excess space along the sides of the motor with foam to reduce vibration
9. Attach an S25 screw with the ridged part facing away from the motor. Fill the drive side with hot glue and quickly press onto the gear; let dry
10. Repeat on the other side with a 6.3 cm screw, placing hot glue on the S25 side, and push it in
11. Slide a nut onto the other side and attach S25 + T01 pieces, facing each other. Add a locking nut and secure tightly
12. Fill the gap between the wheels with hot glue, keeping it level to increase the surface area of the rotating part

Magnet Installation

13. Attach the 3 × 3 cm neodymium magnets opposite each other on the wheels; ensure the same polarity faces outward
14. Attach 4 circular neodymium magnets in a square pattern and fill remaining gaps on each side, keeping polarity consistent

Vertical Supports

15. Place 2 vertical Jenga blocks on either side of the baseboard along the edges, 3.5 cm apart

16. Drill pilot holes from the bottom and screw the vertical Jenga blocks into place
17. Hot glue 2 × 2 cm clay cubes on top of each vertical support, and another clay cube centered between the two supports

Copper Coil Stand

18. Roll the copper wire into a coil approximately 8 cm in diameter
19. Bend D09 pieces around the coil and clay cubes, forming a U-shape to hold the coil
20. Mark the pilot hole locations, then drill and secure the U-shaped holders with screws cut in half
21. Ensure the coil is evenly spaced and stable on the vertical supports

Horizontal Stand & Axle Placement

22. Place the motor and axle assembly on the horizontal Jenga stands
23. Cut 2 X3 pieces in half to create L-shaped supports. Center the axle and motor, mark the positions, and drill pilot holes
24. Screw the L-shaped supports into the horizontal Jenga blocks to hold the axle in placeVertical Axle Support
25. Use E5 pieces (x2) to create a box-like vertical support
26. Attach an A6 and a nut through the box to align with the axle screw
27. Mark and drill a pilot hole on the baseboard without going through it
28. Place a 1.5 × 1.5 cm cardboard piece under the hole for support
29. Cut another screw in half and secure the box-like vertical support to the baseboard
30. Attach B805 (trimmed) to the support so it aligns with the axle. Apply super glue and press firmly

Final Assembly

31. Place a horizontal Jenga block between the vertical box supports. Drill a pilot hole and secure with a flush screw
32. Ensure the motor, axle, and coil are all aligned, free to rotate, and not touching other components
33. Check that all screws, nuts, and glue connections are tight but allow rotation where necessary
34. Test the motor briefly to ensure smooth rotation without wobbling.
35. Confirm the copper coil is properly positioned around the rotating magnets
36. Add any additional foam or clay supports to reduce vibration if needed
37. Connect the motor to a power source and test

Procedure for Testing both heaters:

1. Gather materials; both heaters, infrared thermometer, power source, timer
2. Find a small room removing any hazardous materials (anything flammable or combustible)
3. Place whichever heater being tested first on the floor ensuring safe distance away from any flammable objects
4. Using the infrared thermometer, take the temperature of the room
5. Recording it on a sheet of paper
6. Plug in the power source to an outlet and attach whichever heater is being tested first
7. Turn on the heater and set a timer for 1h
8. Leave the room and close the door
9. After an hour is over return back to the room taking the temperature using the infrared thermometer not pointed directly at the heater but in the general space of the room
10. Turn off the power source
11. Wait for the room to cool back down before repeating the test again from a total of 3 times of each heater

Observation table:

Type of Heater	Time ran for (1hour)	Starting temp degrees (K)	Final temp (K)
12V heater	1h	297.1	347.2
12V heater	1h	296.1	347.8
12V heater	1h	297.3	345.4
Average		296.8	346.8

Type of Heater	Time ran for (1hour)	Starting temp degrees (K)	Final temp (K)
Lenz Law heater/ 6V	1h	295.7	310.9
Lenz Law heater/	1h	295.6	307.8

Type of Heater	Time ran for (1hour)	Starting temp degrees (K)	Final temp (K)
6V			
Lenz Law heater/6V	1h	296.1	311.2
Average		295.8	310

For the analysis lets summaries all the factors and variables:

Variable Type	**Variable**	**Value / Description**	**quation / Calculatio**
Room Information	Room length	157.2 cm	—
	Room width	54.3 cm	—
	Room height	80.6 cm	—
	Room volume (Vroom)	0.688 m^3	V = Length × Width × Height = 1.572 × 0.543 × 0.806 m^3
	Air density (ρ)	1.2 kg/m^3	—
	Mass of air (m)	0.826 kg	m = ρ × Vroom = 1.2 × 0.688
Manipulated Variables	Type of heater	12V heater	—
	Voltage (V)	12 V	—
	Current (I)	16.6 A	—
	Time heater ran (t)	1 hour (3600 s)	—
Responding Variables	Starting temperature (T_1)	297.1 K	—
	Final temperature (T_2)	347.2 K	—
	Temperature change (ΔT)	50.1 K	$\Delta T = T_2 - T_1 = 347.2 - 297.1$
	Energy absorbed by air (Qair)	41,589.51 J	Qair = m × c × ΔT = 0.826 × 1005 × 50.1
	Heater efficiency	5.79 %	η = (Qair / Eelectric)

	(η)		× 100% = (41589.51 / 717120) × 100
Controlled Variables	Specific heat capacity of air (c)	1005 J/(kg·K)	—
	Air pressure	88.6 kPa	—
Calculated Steps	Electrical energy supplied (electric)	717,120 J	Eelectric = V × I × t = 12 × 16.6 × 3600

Commercial heater	Efficiency	Average
Test 1	5.79 %	5.80%
Test 2	5.98%	
Test 3	5.52%	

Analysis

As shown in the data, the Lenz Law heater performed better in terms of efficiency, with an average efficiency of 18.15%. Although it only increased the room temperature by approximately 15 K, the total electrical energy input was significantly lower than that of the commercial heater. Because efficiency is calculated as useful energy output divided by total energy input, the lower power consumption resulted in a higher overall efficiency percentage. In contrast, the commercial heater increased the room temperature by approximately 50 K, which is a much larger temperature change. However, its efficiency was only about 5.80%. The lower efficiency can be better understood by comparing the total energy input and electrical requirements of each heater. The commercial heater operated at 12 V, which is double the voltage of the Lenz Law heater (6 V). However, voltage alone does not determine power. The commercial heater required 16.6 A, while the Lenz Law heater required only 3 A. This means the commercial heater used over five times more current. Using the electrical power relationship P=V×IP = V \times IP=V×I, the commercial heater consumed significantly more electrical power overall. According to Joule's Law, resistive heaters generate heat as electrical current passes through a resistive material. During this process, some energy may be lost through inefficiencies such as heat dissipation into surrounding materials, internal resistance losses, and heat escaping into the environment. Therefore, even though the commercial heater produced a larger temperature increase, it required substantially more electrical energy to do so, resulting in a lower calculated efficiency compared to the Lenz Law heater.

Conclusion: In conclusion, my hypothesis was supported as the Lenz Law heater proved more efficient than the conventional resistive heater. This is because, in a resistive heater, electrical energy is lost as electrons flow through resistive materials, producing heat along the path. In contrast, the Lenz Law heater uses magnetic induction to create eddy currents in the conductor, which efficiently converts the motion of these currents into thermal energy with minimal energy loss.

Application:Based on the experiment results, a Lenz Law heater proved to be much more efficient than a standard 12V heater. If we are able to scale this model up, I have no doubt that its efficiency and performance would improve even further. Transitioning to a heater that uses less energy while maintaining heat output could have significant benefits. As Canadians, we experience cold weather for the majority of the year, and many families struggle to keep their homes warm due to financial constraints. A heater based on this design could help families avoid choosing between staying warm at night and affording groceries. These heaters also have a long lifespan and are relatively easy to maintain, as over time, magnets lose some of their polarity due to heating. Additionally, ethical methods now exist to recycle neodymium magnets with minimal environmental impact.

I am aware that EMFs (eddy currents) can have negative effects on the nervous system, as moving electrons may pose a risk of electrical shocks. If Lenz Law heaters were implemented on a larger scale, these risks could become relevant. However, many of these concerns can be mitigated in household settings, as heaters are typically located in basements or areas away from main living spaces. The effects of EMFs generally occur over extended periods, but in this design, the eddy currents are not left floating freely—they are harnessed to heat the coil, which then transfers thermal energy into the room through a fan.

I believe that creating a Lenz Law heater on a larger scale would be highly beneficial and could serve as a more efficient and sustainable alternative to conventional heating methods.

Source of error: Several sources of error may have influenced the results of this experiment. One potential source of error was the construction of the heater itself. Wooden materials were primarily used as structural supports, and these materials may have absorbed some heat during operation. This could have reduced the measurable heat output in the room, affecting the calculated efficiency.

Another possible source of error was the use of copper wire instead of copper tubing. Copper tubing would have provided a greater surface area, which may have allowed for more efficient heat transfer. The smaller surface area of the copper wire could have limited the overall heating performance.

The experiment was conducted in a closet that was not completely air-sealed. Gaps around the door and other openings may have allowed heat to escape, lowering the recorded temperature increase which ultimately affects the calculated efficiency.

There were also limitations in the design process. This heater was built using a Lenz Law–based approach, where I struggled to find existing reference models or viable designs to use for comparison. As a result, the construction process relied heavily on trial and error not a set procedure, which may have introduced inconsistencies.

Finally, a theoretical error calculation can not be completed because no established theoretical model or prior research on this specific Lenz Law heater design was available, there was no theoretical value against which to compare the experimental results.

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Because of this project I was able to learn many things about how modern heaters works and truly spend time looking at them rather then just turning it on and calling it a day. I was able to truly appreciate all the time and effort that goes into building the heaters that warm us all.

Majority work was done straight on the platform

DID work and Didnt work:

- Powerful magnets too strong slipping and pulling each other off during initial stages of testing
- Was able to use the large magnets for testing but for modeling and purposes switched to less powerful magnets
- Copper tubing heated up and was able to warm a small room
- Had to end up making a model heater due to safety and material
- When using the 3x3 cm magnets there was a lot and vibration due to the axle being unbalanced from the hot glue

- The prototype broke at least 4 times for different reasons each time such as weak axle joint, weak vertical stand, magnets did not pass clearance and hit the copper tubing causing it to break, magnets slipping off, ect.

Google Gemini was used to double check facts insuring the wording in my own words did not go against the concepts explored and for grammar errors. All research was done in my own words, only thing copied are the formulas.

APA formatting was used for citations

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