A Battery With An Emf Of 12 V Is Connected To A 545- Resistor. How Much Energy Is Dissipated In The Resistor

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Understanding the energy dissipation in electrical components is fundamental in physics and electrical engineering. When a battery with a specified electromotive force (emf) is connected to a resistor, the resistor converts electrical energy into heat, which is dissipated into the surroundings. In this article, we explore how to calculate the amount of energy dissipated in such a scenario, focusing on a 12 V emf battery connected to a 545-ohm resistor. We will delve into the concepts of emf, resistance, current, power, and energy, providing detailed explanations and step-by-step calculations.

Fundamental Concepts in Electrical Circuits

Before calculating the energy dissipated, it is essential to understand some fundamental electrical concepts.

Electromotive Force (Emf)

- The emf of a battery, measured in volts (V), represents the maximum potential difference the battery can provide when no current flows.
- It signifies the energy supplied per unit charge by the battery.

Resistance (R)

- Resistance, measured in ohms (Ω), quantifies how much a component opposes the flow of electric current.
- Higher resistance means less current for a given emf.

Current (I)

- Current, measured in amperes (A), is the rate of flow of electric charge.
- Ohm’s Law relates emf, resistance, and current:

$$
I = \frac{E}{R}
$$

where E is emf and R is resistance, assuming ideal conditions without internal resistance.

Power Dissipation (P)

- Power dissipated in a resistor is the rate at which energy is converted into heat.

- It can be calculated using:

$$
P = I^2 R
$$

or

$$
P = \frac{V^2}{R}
$$

where V is the voltage across the resistor.

Energy Dissipated (E)

- Total energy dissipated over a period t is:

$$
E = P \times t
$$

- For continuous operation, the energy per unit time (power) suffices, but for total energy over a specific duration, multiply by time.

Step-by-Step Calculation

Given data:
- Emf of battery, $E = 12\,V$
- Resistance, $R = 545\,\Omega$

Assuming the battery's internal resistance is negligible or the emf equals the terminal voltage, which simplifies calculations.

Step 1: Calculate the Current (I)

Using Ohm's Law:

$$
I = \frac{E}{R} = \frac{12\,V}{545\,\Omega}
$$

Calculating:

$$
I \approx 0.02202\,A
$$

or approximately 22.02 milliamperes.

Step 2: Calculate Power Dissipated (P)

Using the power formula:

$$
P = I^2 R
$$

Plugging in the values:

$$
P = (0.02202)^2 \times 545
$$

Calculating:

$$
P \approx 0.0004849 \times 545 \approx 0.264\,W
$$

Alternatively, using the voltage across the resistor:

$$
P = \frac{V^2}{R} = \frac{12^2}{545} = \frac{144}{545} \approx 0.264\,W
$$

Both methods yield approximately 0.264 watts.

Step 3: Determine Total Energy Dissipated

The total energy depends on the duration of the circuit operation. For illustrative purposes, consider a specific time period, such as 1 hour (3600 seconds).

$$
E = P \times t = 0.264\,W \times 3600\,s
$$

Calculating:

$$
E \approx 950.4\,J
$$

Therefore, in one hour, approximately 950.4 joules of energy are dissipated as heat in the resistor.

Implications and Practical Considerations

Understanding how much energy is dissipated in a resistor is crucial for designing electrical systems, ensuring components are rated appropriately, and managing thermal effects.

Efficiency of the Circuit

- Since all the electrical energy supplied by the battery is converted into heat within the resistor (assuming ideal conditions), the efficiency concerning energy transfer is effectively 100%.
- However, in real scenarios, batteries have internal resistance, which

causes some energy to be lost as heat within the battery itself.

Impact of Internal Resistance

- If the battery's internal resistance, r, is significant, the voltage across the external resistor would be less than emf.
- The actual current would then be:

$$
I = \frac{E}{R + r}
$$

- Consequently, the power dissipated in the resistor would decrease slightly, and some energy would be dissipated internally within the battery.

Thermal Management

- Resistors dissipate heat proportional to the power calculated.
- For continuous operation, adequate cooling measures should be implemented to prevent overheating.
- Using resistors with appropriate power ratings ensures safety and longevity.

Additional Factors Affecting Energy Dissipation

While the above calculations assume ideal conditions, real-world applications involve additional factors:

- **Internal Resistance of the Battery:** As mentioned, batteries have internal resistance that causes additional energy loss.
- **Temperature Effects:** Resistance can vary with temperature, affecting power dissipation.
- **Variable Load Conditions:** Changes in resistance or emf during operation can alter current and energy dissipation rates.
- **Energy Losses in Connectors and Wires:** Resistance in wiring adds to overall energy loss.

Summary

In conclusion, when a 12 V emf battery is connected to a 545-ohm resistor, approximately 0.264 watts of power are dissipated as heat in the resistor under ideal conditions. Over an hour, this corresponds to about 950 joules of energy being converted into thermal energy. This calculation underscores the importance of understanding electrical parameters and their interplay in circuit design and analysis.

Practical Applications

- Designing resistive heating devices.
- Calculating power ratings for resistors in electronic circuits.
- Estimating thermal effects in electrical components.
- Ensuring energy efficiency in electrical systems.

Final Thoughts

Properly analyzing energy dissipation helps engineers and physicists optimize circuit performance, improve safety standards, and develop more efficient electronic devices. Whether for educational purposes or practical applications, understanding these principles is fundamental to mastering electrical circuit analysis.

Frequently Asked Questions

What is the power dissipated in the resistor when a 12 V emf is connected across a 545 Ω resistor?

The power dissipated can be calculated using $P = V^2 / R$, which gives $P = (12)^2 / 545 \approx 0.264$ W.

How much energy is dissipated in the resistor over a period of 1 hour?

Energy dissipated = Power × time = 0.264 W × 3600 s ≈ 950.4 Joules.

If the emf remains the same, how does increasing the resistance affect the energy dissipated over time?

Increasing resistance decreases the current and power dissipated, thus reducing the total energy dissipated over a given time period.

What is the current flowing through the resistor when connected to a 12 V emf?

Using Ohm's law, $I = V / R = 12\ \text{V} / 545\ \Omega \approx 0.0220$ A or 22.0 mA.

Is all the energy supplied by the emf dissipated as heat in the resistor?

Yes, in an ideal circuit, all the electrical energy supplied by the emf is converted to heat energy in the resistor.

How would the energy dissipation change if the emf

were increased to 24 V with the same resistor?

The power would increase by a factor of four (since $P \propto V^2$), leading to four times more energy dissipated over the same period, i.e., approximately 3.84 W and 3,801.6 Joules per hour.

What is the significance of the resistor's resistance value in terms of energy dissipation for a given emf?

A higher resistance results in lower current and less energy dissipation, whereas a lower resistance leads to higher current and more energy being converted to heat in the resistor.

Additional Resources

A Battery With An Emf Of 12 V Is Connected To A 545-Ω Resistor. How Much Energy Is Dissipated In The Resistor

Understanding the flow of electrical energy and its dissipation within resistive components is fundamental in both theoretical physics and practical electrical engineering. In this article, we analyze a simple yet insightful problem involving a battery with an electromotive force (emf) of 12 volts connected across a 545-ohm resistor. Our goal is to determine how much energy is dissipated in the resistor, delving into the underlying principles, calculations, and implications of such a setup.

Introduction to Electromotive Force and Resistance

Electromotive Force (emf) Explained

Electromotive force, or emf, is a measure of the energy supplied by a source per unit charge as it moves through the circuit, typically expressed in volts. It represents the maximum potential difference the source can provide when no current is flowing. For the case at hand, the battery's emf is 12 V, indicating it can, in ideal circumstances, provide 12 joules of energy per coulomb of charge.

Resistance and Its Role in Circuits

Resistance (measured in ohms, Ω) quantifies how much a component opposes the flow of electric current. The resistor in this problem has a resistance of 545 Ω, which influences the current flowing through the circuit and the energy dissipation. According to Ohm's law, the current depends on the emf and the resistance:

\[I = \frac{V}{R} \]

where V is the emf and R is the resistance.

Analyzing the Circuit: Basic Principles

Ohm's Law and Current Calculation

Given that the emf of the battery is 12 V and the resistor is 545 Ω, assuming an ideal circuit with no internal resistance or other components, the current I can be calculated straightforwardly:

$$I = \frac{V}{R} = \frac{12\, \text{V}}{545\, \Omega}$$

Calculating this yields:

$$I \approx 0.02202\, \text{A}$$

or approximately 22.02 milliamperes. This current value indicates the flow of charge through the resistor per second.

Energy Dissipation in Resistors

Resistors convert electrical energy into heat, and the rate at which this energy is dissipated is given by Joule's law:

$$P = I^2 R$$

where P is the power dissipated in watts.

Calculating Energy Dissipated in the Resistor

Step 1: Power Dissipation

Using the current calculated:

$$P = I^2 R = (0.02202\, \text{A})^2 \times 545\, \Omega$$

$$P \approx (0.0004848) \times 545$$

$$P \approx 0.2643\, \text{W}$$

This indicates the resistor dissipates approximately 0.2643 watts of power continuously when the circuit is operational.

Step 2: Energy Over Time

To determine the total energy dissipated, we need to specify the duration the circuit is active. For example, over a period of t seconds, the energy E dissipated is:

$$E = P \times t$$

Suppose the circuit operates for 1 hour (3600 seconds):

$$E = 0.2643\, \text{W} \times 3600\, \text{s}$$

$$E \approx 952.9\, \text{J}$$

Thus, about 953 joules of energy are converted into heat in the resistor during this period.

Alternative Method: Using Electrical Energy and Charge

Calculating Total Charge Flow

Another approach involves calculating the total charge Q passing through the resistor:

$$Q = I \times t$$

For a duration of 1 hour:

$$Q = 0.02202\, \text{A} \times 3600\, \text{s} \approx 79.27\, \text{C}$$

Since emf supplies energy per coulomb:

$$\text{Total energy supplied by the battery} = V \times Q = 12\, \text{V} \times 79.27\, \text{C} \approx 951.2\, \text{J}$$

This aligns closely with the previous calculation, confirming that nearly all energy supplied by the battery is dissipated in the resistor as heat, assuming negligible internal resistance.

Implications and Practical Considerations

Efficiency and Energy Loss

In real circuits, resistors convert electrical energy into heat, which is often undesirable if the goal is efficient energy transfer. This example highlights that a significant portion of the energy supplied by the battery is dissipated as heat in the resistor—approximately 953 joules per hour in our calculation.

Pros:

- Simple calculations based on Ohm’s law and Joule’s law provide clear insights.
- Highlights the relationship between emf, resistance, current, and energy dissipation.
- Demonstrates how energy transfer and dissipation occur in resistive elements.

Cons:

- Assumes ideal conditions; in real circuits, internal resistance and other factors affect calculations.
- Does not account for battery internal resistance, which would reduce the current slightly.
- The power dissipation could lead to heating issues in practical applications.

Features and Applications

- Thermal Management: Understanding energy dissipation helps in designing heat sinks and cooling systems.
- Energy Efficiency: Recognizing the amount of energy lost as heat allows engineers to optimize circuit components.
- Power Ratings: Resistors must be rated to handle the dissipated power safely to prevent damage.

Advanced Considerations and Real-World Factors

Internal Resistance of the Battery

In practical scenarios, batteries have internal resistance, which means the actual emf is slightly less than the emf measured under ideal conditions. This internal resistance causes additional voltage drops and affects current calculations, slightly reducing the energy dissipated in the external resistor.

Variable Resistance and Nonlinear Components

Real resistors may have temperature-dependent resistance, which can change the current and energy dissipation over time. Nonlinear elements like diodes or transistors would complicate calculations further, requiring more detailed circuit analysis.

Transient Effects

If the circuit is switched on or off suddenly, transient effects such as inductance and capacitance may influence current flow and energy dissipation temporarily before reaching steady-state conditions.

Conclusion

To summarize, in the given circuit with a 12 V emf battery connected to a 545-Ω resistor, approximately 0.2643 W of power is dissipated as heat during continuous operation. Over an hour, this results in roughly 953 joules of energy lost in the resistor. These calculations demonstrate fundamental principles of electrical energy transfer, highlighting the importance of resistance in controlling current and managing energy dissipation. While idealized models provide a solid foundation, practical applications necessitate considerations of internal resistances, thermal effects, and efficiency. Understanding these concepts is crucial for designing safe, efficient, and reliable electrical circuits across various engineering disciplines.

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