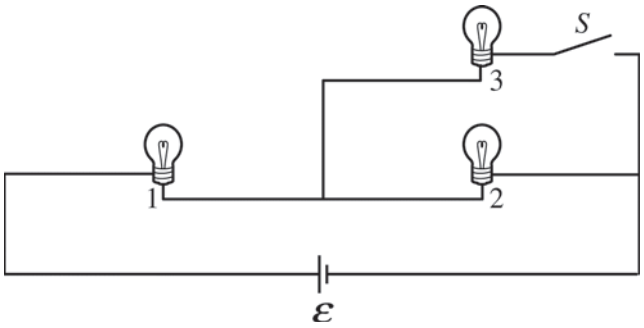

2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: "Bulb 1 will decrease in brightness when the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 1 ? Qualitatively explain your reasoning.

ii. Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1.

iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

(b) A student makes the following prediction about bulb 2: "Bulb 2 will decrease in brightness after the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 2 ? Explain your reasoning in words.

ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.

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Question 2

12 points total | **Distribution of points**

(a)

i) 3 points

For indicating that R_{eq} of the entire circuit or the combination of bulbs 2 and 3 decreases — 1 point

For indicating a change in I_{tot} or the potential difference across bulb 1 consistent with Ohm's law and the change in R_{eq} stated in the response — 1 point

For indicating a change in brightness consistent with the current or potential difference change stated in the response — 1 point

ii) 3 points

For indicating that $P_1 = \frac{1}{4}\left(\mathcal{E}^2/R\right)$ — 1 point

For indicating that the new equivalent resistance of the circuit is $R_{eq,new} = (3/2)R$ — 1 point

Note: Credit is earned if calculation is done in part (i) and used here.

For manipulating equations to show that the power expended by bulb 1 is $P_{new} = \frac{16}{9}P_1$ — 1 point

iii) 1 point

For using or referring to the expression from part (a)(ii) to support the claim made in (a)(i) regarding the brightness of bulb 1: e.g., $16/9 > 1$, and indicating an understanding that brightness is related to power consumption — 1 point

(b)

i) 1 point

For explaining that the brightness of bulb 2 decreases after the switch is closed because it expends less power (or the current through bulb 2 decreases, or the potential difference across bulb 2 decreases) — 1 point

ii) 1 point

For a calculation that supports the reasoning in part i — 1 point

Question 2 (continued)

Distribution of points

(c) 3 points

For indicating in either part (c)i or part (c)ii that brightness is dependent on potential difference across the bulb OR on current through the bulb — 1 point

i)

For a reasonable explanation for why bulb 1 is brighter than bulb 2 — 1 point
Example: Immediately after the switch is closed, the potential difference across the capacitor will be zero (like a short in the circuit), so the current through bulb 2 would be zero, which is less than the current through bulb 1.
Note: No points will be awarded for indicating that bulb1 is brighter than bulb 2 with no justification.

ii)

For a reasonable explanation for why bulb 1 is the same brightness as bulb 2 — 1 point
Example: The current through bulb 2 increases as the potential difference across the capacitor increases (becomes like an open circuit), so a long time after the switch is closed, the current through bulb 2 will be equal to the full current through bulb 1.
Note: No points will be awarded for indicating that bulb 1 is the same brightness as bulb 2 without a justification.