Current Electricity

An Introduction to Resistance, Capacitance and Inductance

This problem provides an introduction to current electricity and circuits.

Intended Learning Outcomes

By the end of this activity students should be able to:

- Define DC circuits and the way in which current flow in them
- Use circuit diagrams and symbols correctly
- Understand basic electrical components (resistors, inductors, and capacitors)
- Define AC circuits and the way in which current flows in them
- Draw analogies with mechanical response phenomena

KEYWORDS:

AC circuits, capacitance, circuit diagrams, circuit symbols, DC circuits, electric current, electricity, emf, inductance, LCR circuits, resistance.

Contents

Reading List

The following textbooks are suggestions, other equivalent textbooks are available:

- Breithaupt, J. ***Physics***. Palgrave Foundations.
- Tipler, P.A. ***Physics for Scientists and Engineers***. Freeman.

This problem is adapted from an on-line knowledge enhancement module for a PGCE programme. It is used to cover the basics of circuits with resistance, capacitance and inductance. The original material can be found at:
http://open.jorum.ac.uk/xmlui/handle/123456789/2970

Problem Statement

Heart defibrillators, which are used to restore a regular heart beat, stimulate the heart to contract by delivering a short current pulse of duration 20 ms. In one type of defibrillator a capacitor is charged to a suitable voltage and then discharged through the patient's chest with the aid of two large electrodes. The defibrillator needs to be able to deliver pulses of up to 360 J to patients with transchest resistances ranging up to 150 ohms.

Estimate values for capacitance and voltage needed to cope with these requirements.

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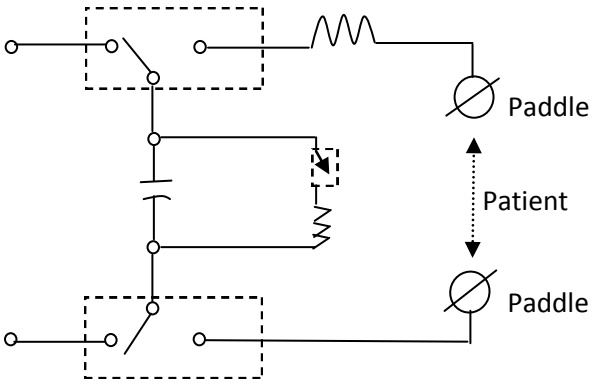


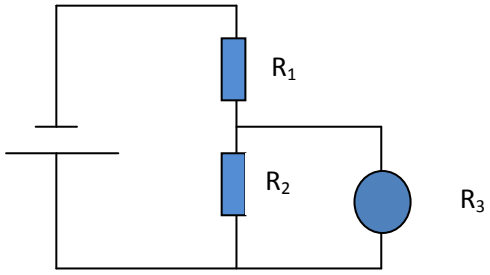
The figure shows a typical defibrillator circuit.

Suggested Deliverables

???

Questions for Class Discussion

1. Potential divider: The battery has an emf of 2V. What does the voltmeter across the second resistor measure when the resistors are R_1 = 2kΩ and R_2 = 4kΩ? Enter your answer without units as an integer or a fraction in volts.

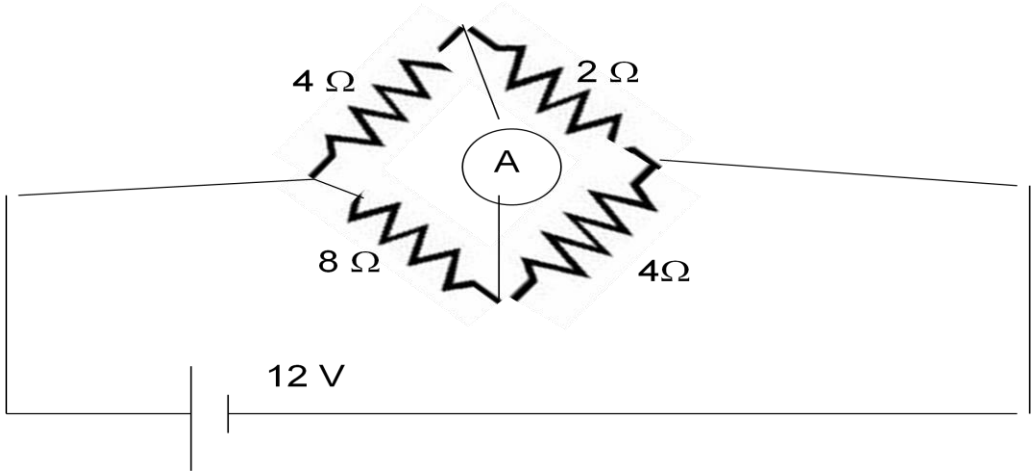


2. If the voltmeter has a finite resistance 10 kΩ what is the total resistance of the circuit?

3. Estimate of the resistance of a 60 W domestic light bulb.

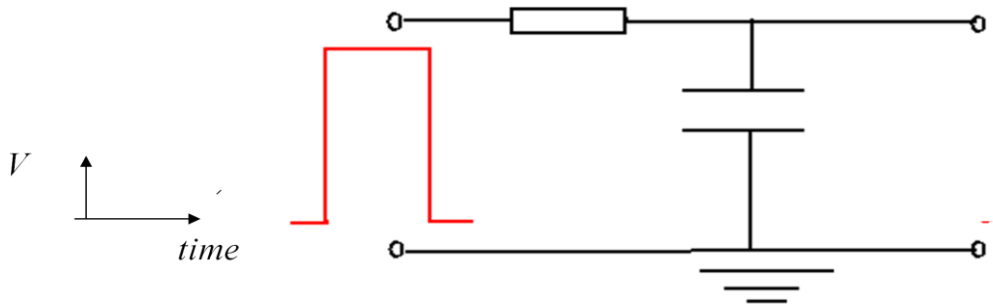
4. To save money it is suggested I cut the 1kW element of my electric heater in half. Am I right to reject the suggestion?

5. What does the ammeter read in the following diagram?

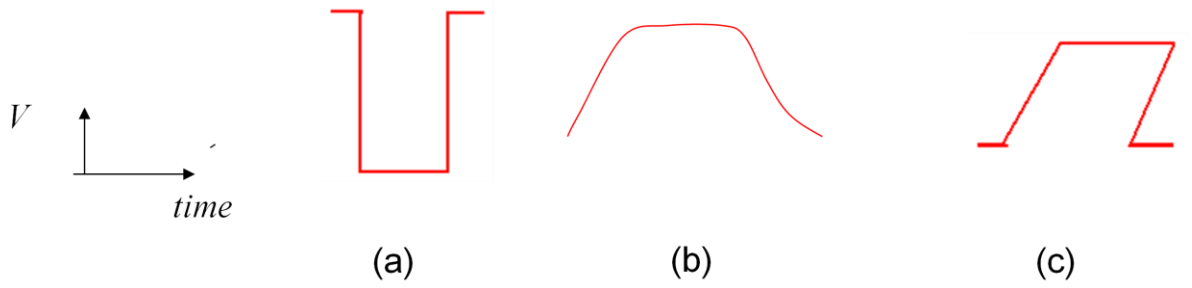


6. A CR series circuit is connected to a battery, voltage *V*, by closing a switch. Once the connection is made what is the energy delivered by the battery in charging the capacitor? Compare this with the energy stored in the capacitor when it is fully charged to the voltage *V*. Where is the missing energy?

7. Which of (a) – (c) is the output signal for the circuit shown in the figure for the given input?



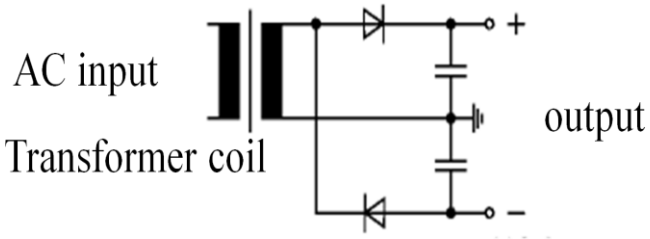
Outputs:



8. Why does switching off a high current circuit produce a spark

9. What changes would you make to increase the resonant frequency of an LCR circuit?

10. The Cockcroft-Walton generator was used to produce high voltages in the first splitting of the atom, although it was actually invented somewhat earlier by the Swiss physicist Heinrich Greinacher



Massive Cockroft-Walton, hackerfriendly's photostream as posted on www.flickr.com, Creative Commons Licensed

How does the circuit produce a DC voltage at output that is doubling the peak to peak AC voltage at input? How is this consistent with conservation of energy?

Individual Exercises

1. ***Resistance***
   (a) A circuit contains a battery with zero internal resistance, voltage V_0, and resistances r and R in series. What is the voltage V across the resistor R?
   (b) A voltmeter with resistance R' is now connected across R. What is the combined resistance of the circuit? What voltage drop does the voltmeter measure? Show that for $R' >> R$ the voltmeter measures V.

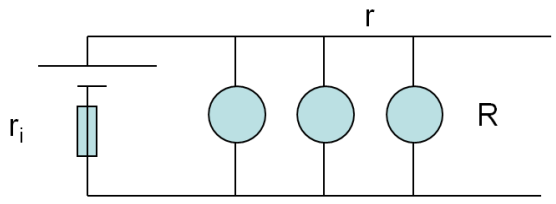
2. ***Current***
   An ammeter with internal resistance r is put in series with a resistance R and a battery with voltage V. Find the current in the circuit. Show that the ammeter does not affect the current if $r << R$.

3. ***Simple Harmonic Motion***
   A capacitor, capacitance C, is given an initial charge and then connected to an inductor, inductance L. Write down the energy in the capacitor if it has charge Q and the energy in the inductor when the current in the circuit is I. Hence write down an equation for the conservation of energy. Argue that as the charge on the capacitor decreases the current in the inductor increases and vice-versa and hence that the charge and current oscillate 90 degrees out of phase.

4. ***Capacitance***
   A Ni-Cd AA size battery stores around 4000J of energy which it delivers at 1.2V. What capacitance would be required to store this energy at the same voltage? Is this practical with a parallel plate capacitor?

5. ***Transformer***
   An AC voltage is amplified by a transformer. Obtain an algebraic relation between currents in the secondary and primary and the numbers of turns.

6. ***DC Electricity***
   In the late 1870s Edison's invention of the electric light bulb caused shares in gas companies to plummet. This prompted William Preece to claim that centrally supplied electricity could never replace gas as a source of domestic lighting. His conclusion was that the energy dissipated by each of n lamps would be inversely proportional to n^2. The simple d-c circuit which was considered by Preece is shown in the figure.



   (a) How much power is dissipated in each bulb?
   (b) In Edison's original electricity supply utility $r+r_i$ was a fraction of an ohm and the resistance of an Edison lamp was about 200 ohms when hot. Sketch the energy dissipated in a lamp as a function of n, and hence estimate how many light bulbs would have to be in the circuit to make Preece's conclusion valid.

7. ***Impedance Matching***

A battery has internal resistance *r* and E.M.F. *V* Is connected to a circuit of resistance *R*. What value of *R* will maximise the power dissipated in the external circuit? Notice that this also maximises the power dissipated in the battery!

8. ***Contact Time***

A golf equipment manufacturer requires a device to measure the contact time between a golf ball and a club. He proposes to do this by covering the ball and club in an electrical conductor (e.g. aluminium foil) and constructing a circuit containing a capacitor of capacitance *C* and resistor, resistance *R*, in parallel, which is closed during the contact between the ball and club. Before impact the capacitor is charged; during impact the capacitor discharges. Find the relationship between the initial and final charge on the capacitor and the time of contact.