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# CURRENT ELECTRICITY

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INTRODUCTION TO RESISTANCE, CAPACITANCE AND INDUCTANCE

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## PREAMBLE

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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>

This unit was run over one week with on-line support.

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## INTENDED LEARNING OUTCOMES

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By the end of the module 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

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## READING LIST

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The reading list is that provided for the original module. Other equivalent textbooks are available.

### READY TO STUDY

- Breithaupt, J., *Physics*. Palgrave Foundations.

### ESSENTIAL

- Tipler, P.A., *Physics for Scientists and Engineers*. Freeman.

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# PROBLEM STATEMENT

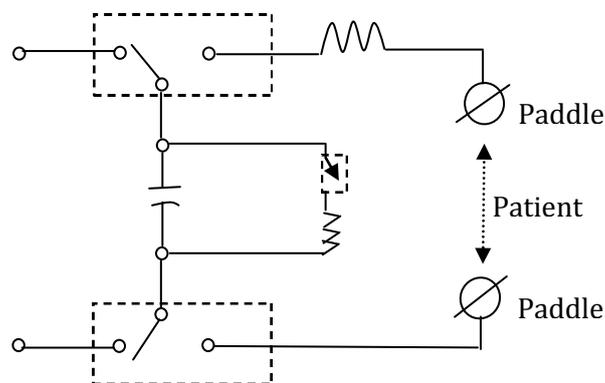
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Heart defibrillators, which are used to restore a regular heart beat, stimulate the heart to contract by delivering a short current pulse of duration 20 ms. In one type of defibrillator a capacitor is charged to a suitable voltage and then discharged 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 transthoracic resistances ranging up to 150 ohms.

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



AED Training and CPR Training, Frederick Md Publicity as posted on [www.Flickr.com](http://www.Flickr.com),  
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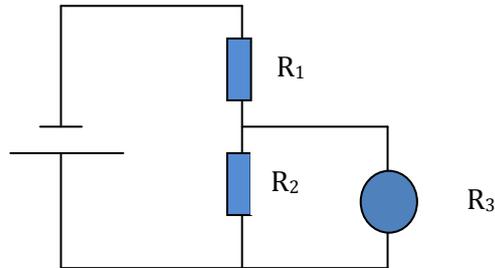
The figure shows a typical defibrillator circuit.

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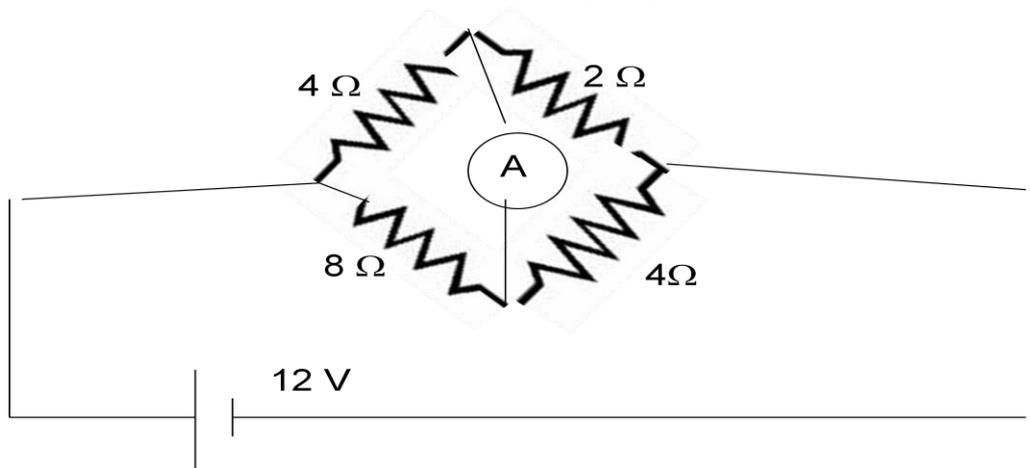
## QUESTIONS FOR CLASS DISCUSSION

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

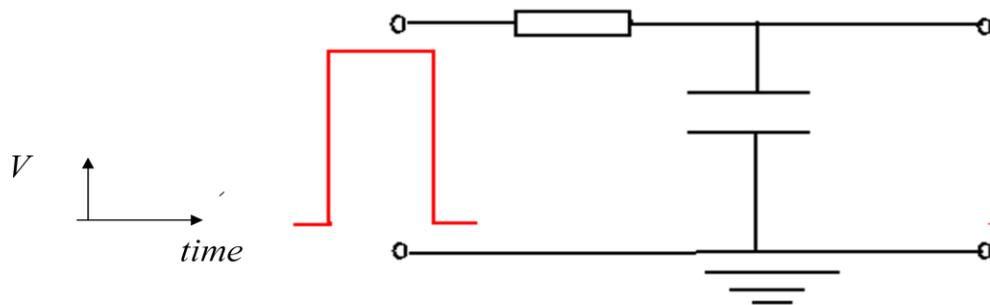


2. If the voltmeter has a finite resistance  $10\text{ k}\Omega$  what is the total resistance of the circuit?
3. Estimate of the resistance of a  $60\text{ W}$  domestic light bulb:
4. To save money it is suggested I cut the  $1\text{ kW}$  element of my electric heater in half. Am I right to reject the suggestion?
5. What does the ammeter read in the following diagram?

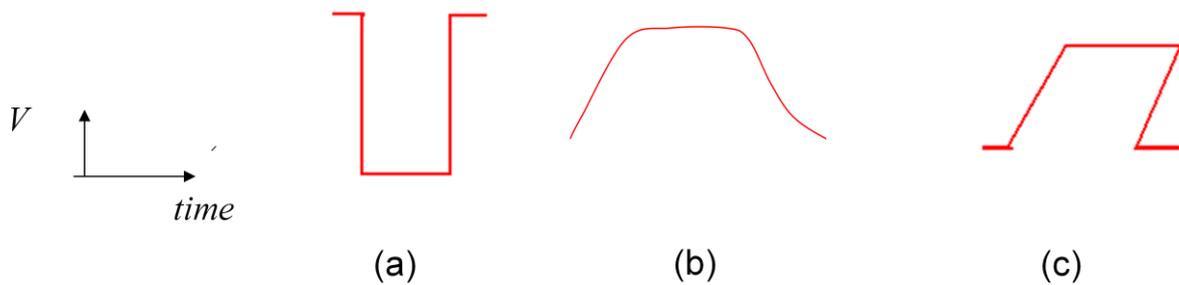


6. A CR series circuit is connected to a battery, voltage  $V$ , by closing a switch. Once the connection is made what is the energy delivered by the battery in charging the capacitor? Compare this with the energy stored in the capacitor when it is fully charged to the voltage  $V$ . Where is the missing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

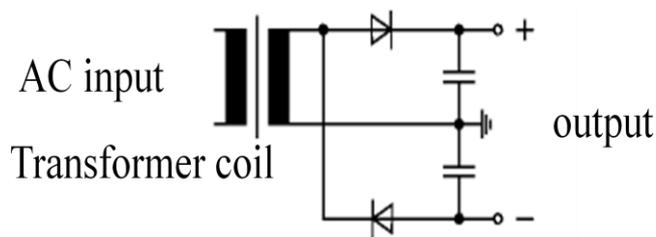
7. Which of (a) – (c) is the output signal for the circuit shown in the figure for the given input?



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 Cockcroft-Walton, hackerfriendly's photostream as posted on [www.flickr.com](http://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?

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# INDIVIDUAL EXERCISES

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## Problem 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  $R' \gg R$  the voltmeter measures  $V$ .

## Problem 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  $r \ll R$ .

## Problem 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.

## Problem 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?

## Problem 5: Transformer

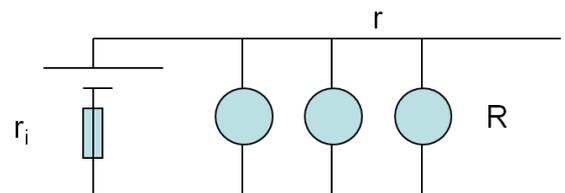
An AC voltage is amplified by a transformer. Obtain an algebraic relation between currents in the secondary and primary and the numbers of turns.

## Problem 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.



**Problem 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!

**Problem 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.