

# University of Toronto

## 2001-2002 Physics Olympiad Preparation Program

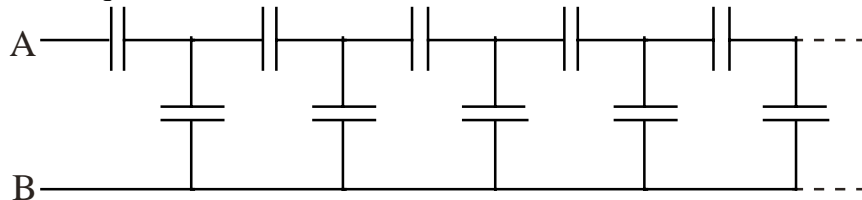
### Problem Set 6: Circuits and (a bit of) Modern Physics

*Due Monday 8 April 2002*

- You need a multimeter or ohmmeter for the last problem. If you don't have one, ask your Physics Teacher or a friend.
- Please be prompt with this problem set; we will be selecting students for our exciting POPTOR training weekend right after the due date.

#### 1) Everyone has the capacity to learn the quadratic formula!

Calculate the equivalent capacitance between points A and B of the following infinite circuit, if all the capacitors are equal and of value  $C$ .



*Hint:* If you got rid of the two left-most capacitors (one horizontal and one vertical), what would the capacitance be of the remaining infinite chain?

*[Isamu]*

#### 2) I always resist getting a shock

You may have noticed warnings on television sets or computer monitors not to mess about inside even if the power is unplugged. This is because there are some large capacitors inside which are charged up to high voltages – a potentially lethal combination. Large inductors can be equally lethal but in a different way. If you have a circuit with a current flowing through a large inductor, if you try to turn it off by opening a switch there can be spectacular sparks generated by huge voltages across the switch. I work on the ATLAS<sup>1</sup> experiment at the CERN<sup>2</sup> laboratory and we have a very large inductor. It is a superconducting solenoidal magnet 5.3m long and 1.2m in radius. The solenoid is wrapped uniformly with about 1200 turns of superconducting wire which carry a current of 8000A.

- (a) Estimate the magnetic field at the centre of the solenoid.

<sup>1</sup> <http://pdg.lbl.gov/atlas/atlas.html>

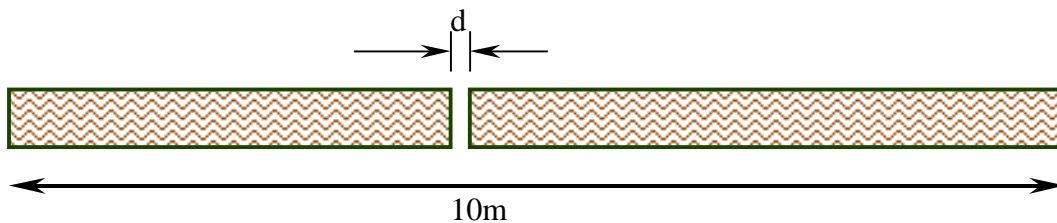
<sup>2</sup> <http://public.web.cern.ch/Public/>, “Where the Web was born!”

- (b) When we talk about “how big” a resistor is, we need to specify both its resistance (in Ohms) and its power rating (in Watts). (The power rating tells us how much power the resistor can dissipate continuously without melting, blowing up, bursting into flames, ... whatever.) How big a resistor would you need to put in series with the solenoid so that if you had to switch the magnet off suddenly, the voltage across the switch would not exceed 80V?
- (c) With the resistor in parallel, how long will it take for the voltage across the open switch to drop to a safe value of 8V?

[David]

### 3) Cracked!

After buying a new TV, I connect it to an satellite dish with a 10m long rubber coated copper wire. I then discover that I have trouble picking up any channel below Channel 19 (500MHz). (I switched to satellite after dealing with that pesky balloon in Problem Set 4, but I seem to be doomed to never manage to get Fraggile Rock.) When I measure the resistance of the wire with a DC ohmmeter I discover it has infinite resistance so I decide it must have a hairline crack of width  $d$  (see figure, not to scale). The reason the low frequency channels can't get through is that



the wire has an RC time constant of about  $1/(500\text{MHz})=2\times 10^{-9}\text{s}$ . What is the width of the crack,  $d$ ?

*Hints:* Assume the sides of the crack are parallel and straight, and that the crack is filled with rubber. The resistivity of copper is  $1.7\times 10^{-8}\Omega\cdot\text{m}$ ; the dielectric constant of rubber is  $\kappa=7$ . Assume all resistances and capacitances other than the wire's are negligible.

[David]

### 4) Gravity isn't Bohring

Some cosmologies allow the possibility that other universes exist in which the forces and constituents differ from our universe. Imagine a universe in which there is no long range electromagnetic force, so the only long range force is gravity. Assume the proton, neutron and the electron exist with exactly the same masses as in our universe, but there are no electromagnetic forces between them. A hydrogen atom would still consist of an electron bound to a proton, but it would only be bound by gravity.

- (a) What would be the energy difference (in electron volts) between the ground state and the first excited state of a hydrogen atom in the imaginary universe without electromagnetism? Assume the value of Planck's and Newton's constants (and all the other laws of physics except for electromagnetism) are the same in the imaginary universe as in our universe.

- (b) Assume the current size of the imaginary universe is about the same as ours (radius  $\sim 10^{10}$  light years). Can gravitationally bound hydrogen atoms exist in the imaginary universe?

[David]

### 5) Resisting the light

When a light bulb heats up, does its electrical resistance go up or down?

Find an unbroken 120V incandescent light bulb; any typical size (15W, 25W, 40W, 60W, 75W, 100W) will do. (If you – temporarily – take a light bulb from a lamp, make sure that the lamp is turned off, unplugged, the bulb has cooled down before removing it, and you have permission from the owner of the lamp.)

- (a) Measure the resistance of the light bulb when it is at room temperature. (Just use an ohmmeter or multimeter; ask your physics teacher for help if you don't have one at home.)
- (b) Calculate the resistance of the light bulb when it is turned on and hot under normal operating conditions. (*Do not try to measure the resistance while the light bulb is plugged into a circuit!* Just calculate the resistance from the bulb's voltage – 120V - and power rating, *e.g.* 60W.)
- (c) Assuming your measurement and calculation are accurate, answer our original question: When a light bulb heats up, does its electrical resistance go up or down?

[David]

## POPBits™ – Possibly useful bits of information

### Constants and units<sup>3,4</sup>

astronomical unit (mean earth-sun distance)	au	149597870660±20 m
atomic mass unit: (mass <sup>12</sup> C atom)/12	<i>u</i>	(1.66053873± 0.00000013)×10 <sup>-27</sup> kg
Boltzmann constant	<i>k</i>	(1.3806503 ± 0.0000024)×10 <sup>-23</sup> J/K
elementary ( <i>i.e.</i> electron) charge	<i>e</i>	(1.602176462 ± 0.000000063)×10 <sup>-19</sup> C
electron (or positron) mass	<i>m<sub>e</sub></i>	(510998.902 ± 0.021) eV/c <sup>2</sup> (9.10938188 ± 0.00000072)×10 <sup>-31</sup> kg
electron volt (eV)	<i>eV</i>	(1.602176462 ± 0.000000063)×10 <sup>-19</sup> J
Newtonian gravitational constant	<i>G<sub>N</sub></i>	(6.673±0.010)×10 <sup>-11</sup> m <sup>3</sup> /kg/s <sup>2</sup>
permittivity of free space	<i>ε<sub>0</sub></i>	8.854187817×10 <sup>-12</sup> F/m
permeability of free space	<i>μ<sub>0</sub></i>	4π×10 <sup>-7</sup> N/A <sup>2</sup>
Planck constant	<i>h</i>	(6.6260755 ± 0.000004)×10 <sup>-34</sup> J·s (4.13566727 ± 0.00000016)×10 <sup>-15</sup> eV·s
proton mass	<i>m<sub>p</sub></i>	(938271998 ± 38) eV/c <sup>2</sup> (1.67262158 ± 0.00000013)×10 <sup>-27</sup> kg
solar luminosity	<i>L<sub>☉</sub></i>	(3.846 ± 0.008)×10 <sup>26</sup> W
speed of light in vacuum	<i>c</i>	299 792 458 m/s
standard acceleration of gravity at the earth's surface	<i>g</i>	9.80665 m/s <sup>2</sup>
Stephan-Boltzmann radiation constant	<i>σ</i>	(5.670400 ± 0.000040)×10 <sup>-8</sup> W/m <sup>2</sup> /K <sup>4</sup>
tropical year (2001)	yr	31556925.2 s

### Great excuses for a party

Most famous physics class demonstration ever

(Oersted discovers that electric currents generate magnetic fields)

April 1820

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<sup>3</sup> <http://physics.nist.gov/cuu/Constants/index.html>

<sup>4</sup> [http://pdg.lbl.gov/2000/contents\\_sports.html](http://pdg.lbl.gov/2000/contents_sports.html)