CAP Student Advisory Council (SAC)
Conseil consultatif des étudiants de l’ACP (CCE)

# 2020 Problem Competition

**Deadline for submission: 2020 September 8, 23h59 EDT**

## Regulations

If your solution is presented in audio or video format, the presentation can be no longer than 10 (ten) minutes.

If your solution is in a written format, it can occupy an area of no more than 467.5 square inches (equivalent to 5 sides of 8.5 x 11 inch “letter” paper). In SI units this is 0.3016 square metres.

The mass of your solution (if measurable) must be no more than 2 (two) kilogrammes.

Your solution, in all aspects, should comply with local health and safety guidelines (including physical distancing, where pertinent).

While you do not need to be an undergraduate affiliate or a graduate student member of the CAP to participate in this challenge, you do need to be someone who would qualify to become an affiliate or graduate student member – as do all members of your team if you choose to participate as a team. You can see the eligibility requirements for undergraduates here: https://www.cap.ca/membership/undergraduate-student-affiliateship/ and for graduate students here: https://www.cap.ca/membership/graduate-student-membership/

While looking at the criteria, consider joining. There is no fee while an undergraduate student and, for graduate students, your first year as a graduate student member is free.

## Adjudication

The solutions will be judged on four (4) criteria:

- physical correctness of your solution (7 marks)
- clarity of your solution (5 marks)
- creativity of your solution (5 marks)
- mathematical correctness of your solution (3 marks)
- judging will be carried out by a team selected by the CAP Student Advisory Council. The judges’ decision is final.

**2020 PROBLEMS**

Choose *one* of the problems and present your solution, in any e-mailable form you choose, to the Director of Student Affairs (bnewling@unb.ca) before 11:59 PM (Eastern) on September 8th, for a chance at problem-solving fame and glory. You may submit your solution individually or as a team, perhaps representing your local Physics Student Society or Science Club.

**Problem One**

A. You may have seen a small spark when you unplug an electronic device like a desktop charger. Explain why a spark occurs when you unplug the device, but not when you plug it in. Would you expect to see a spark to all electric devices? Why or why not?
B. According to Faraday’s Law of Electromagnetic Induction, an electromagnetic coil generates some electromotive force (emf) when placed in a varying magnetic field.
   a. Explain how a magnetic core inserted in the electromagnetic coil increases the magnitude of the produced emf.
   b. In classical electrodynamics, how can the coil “feel” the magnetic field that passes through the magnetic core?
   c. Explain the Aharonov-Bohm (AB) Effect in a way general scientists can understand.
   d. Relate the AB Effect to (b) for an alternative explanation.

**Problem Two**

A stream of water at 20$^{o}$C flows into a lake at a rate of 1 $m^3/s$. The temperature of the lake, which is not disturbed significantly by the stream, is 10$^{o}$C.

a. What is the rate of increase of the entropy of this composite system due to this process, ignoring possible differences in chemical composition? [The density of water is 1000 $kg/m^3$ and the specific heat is 4.18 kJ/(K kg).]
b. Determine the rate at which external work could be performed if the same change of state were performed reversibly. Take the lake to be a suitable thermal reservoir.
c. The river is harnessed for hydro-electric power by erecting a dam and channeling the flow through a turbine. The efficiency of the turbine-generator set is 85%. What height should the dam be in order to generate electrical power at the same rate as in (b).

**Problem Three**

The Tennis Racket (or Intermediate Axis) Theorem.

Sometimes, when you throw an object in the air spinning in a certain direction, you will get an odd revolution in surprising directions.

The most famous demonstration is performed with a tennis racket (but you can try it, carefully, with your phone). If the tennis racket is thrown upward while spinning about an axis that points along its handle, the rotation is stable *i.e.* the axis of rotation stays the same. If the racket is thrown upward while spinning about an axis that is perpendicular to the plane of the racket head, the rotation is also stable. If the racket is thrown upwards while spinning about an axis in the plane of the racket head then the tumbling in unstable (the rotation axis keeps changing).

Explain why this is the case.

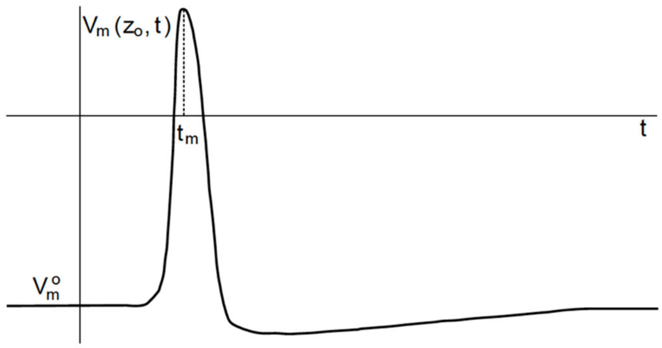
**Problem Four**

The passage of an *action potential* (nerve impulse) along a nerve fibre is marked by a change in the *membrane potential*, $V_m$, that is the potential difference between the fluid inside the nerve cell and the fluid outside the nerve cell. These two fluids are separated by the nerve cell membrane.

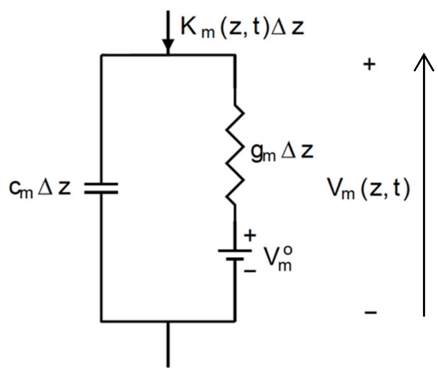
Assume that an action potential is traveling at constant velocity, $v$, in the positive $z$-direction along an axon. Assume that the core conductor model is valid so that

$$\frac{\partial^2 V_m(z,t)}{\partial z^2} = (r_i + r_0) K_m(z,t)$$

The waveform of the propagated action potential at one point in space ($z = z_0$) is shown in the diagram.




a. Sketch $K_m(z,t)$ on the same time scale as $V_m(z,t)$.
b. Show that one **cannot** account for $K_m(z,t)$ by assuming that the membrane can be represented by the equivalent circuit for an incremental element of length $\delta z$ shown in the circuit diagram. The high potential side of the model circuit represents the fluid outside the nerve cell. The low potential side represents the fluid inside the cell. The electrical components model the behaviour of the membrane itself.




$g_m$ and $c_m$ are the constant conductance and capacitance per unit length. [*HINT*: Consider the polarity of the current through the parallel combination of $g_m$ and $c_m$ prior to the time of occurrence of the peak of the action potential, $t_m$.]