Problem Set No. 6

UBC Metro Vancouver Physics Circle 2018

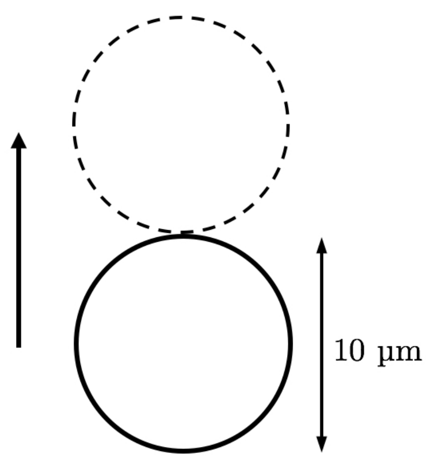
May 31, 2018

Problem 1

Animal cells produce energy via cellular respiration:

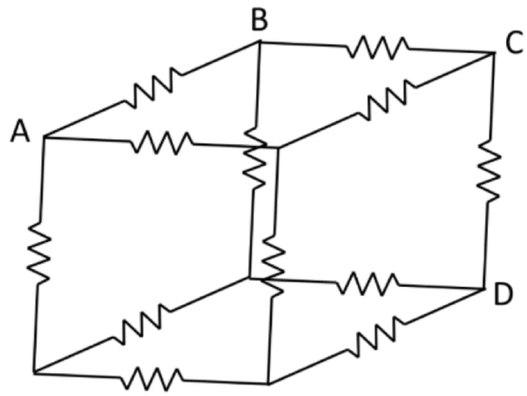
$$C_6H_{12}O_6 + 6\,O_2 + 30\,\mathrm{ADP} + 30\,\mathrm{P}_i \longrightarrow 6\,CO_2 + 6\,H_2O + 30\,\mathrm{ATP}$$

Above, a glucose molecule ($C_6H_{12}O_6$) is fully oxidized to carbon dioxide (CO_2). In the process, adenosine diphosphate (ADP) combines with inorganic phosphate (P_i) to turn into adenosine triphosphate (ATP), which is a molecule cells use for energy. For every mole of glucose that is oxidized by an animal cell, approximately 30 moles of ATP are generated. Given that the conversion of ATP to ADP releases 30.5 kJ/mol, determine the number of glucose molecules a cell requires to lift itself by its own diameter. You can approximate the cell as a sphere of water, 10 µm in diameter. Remember that 1 mole of substance X is equal to 6.02×10^{23} molecules of X.



Problem 2

A circuit consists of a group of 12 identical 100Ω resistors arranged in a cube as shown below. Points A and D are connected to either end of a 12V battery. What is the total resistance of the circuit?



Problem 3

The power generated by a wind turbine is given by

$$P = \eta \, \rho^a \, r^b \, v^c$$

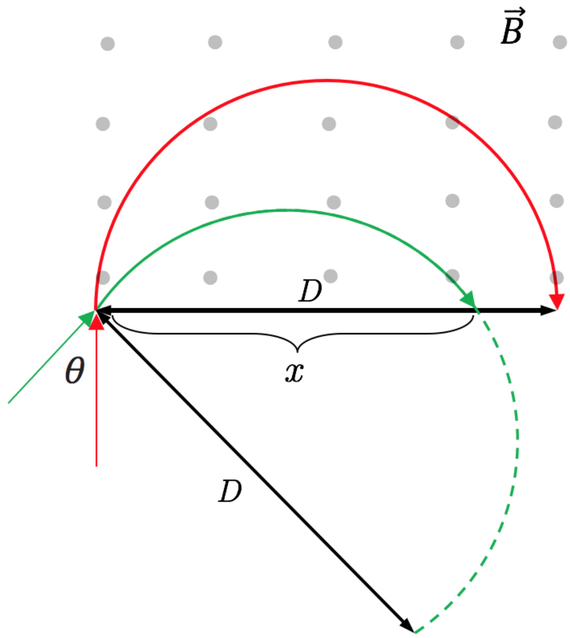
where η is the efficiency of the system (a unitless number), ρ is the density of air, r is the blade length, and v is the wind velocity.

a) Determine the values a, b, and c.

b) If a wind turbine can generate 2 MW of power when the wind blows at 30 km/h, how fast does it need to blow for the turbine to generate 3 MW of power?

Problem 4

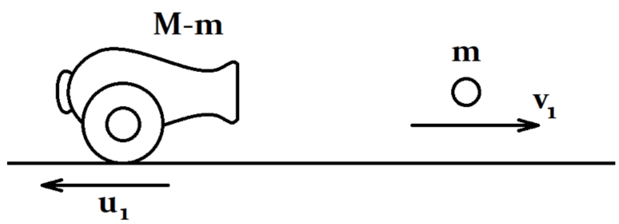
A positively-charged particle of mass m and charge q enters a magnetic field with strength B. This charge enters the field perpendicularly and displaces a horizontal distance D with respect to the edge of the field; its path is depicted by the red colour in the diagram below.



If this same charge enters the field at an angle θ with respect to the vertical axis, what will its horizontal displacement, x, along the edge of the field be?

Problem 5

The Rapid-Fire 5000 is a new line of cannons designed to hold N cannon balls, each having a mass of m, and itself having a mass of M. This design is unique in a way that it shoots one cannon ball each second, with the cannonballs exiting at muzzle speed v_b, **with respect to the cannon**. A group of physicists are recruited to experiment with the Rapid-Fire 5000 over a frictionless surface. They orient the cannon horizontally and let the bombarding begin! In this problem, we will study the motion of cannonballs and the cannon as it undergoes rapid fire. The diagram below depicts the first shot.



a) Find the velocity of the cannonball (v_1) and the velocity of cannon (u_1) after the first shot.

b) Find the velocity of the i^{th} cannonball (v_i) and the velocity of cannon (u_i) after the i^{th} shot, as a function of v_{i-1} and u_{i-1}. Note: $i \leq N-1$

c) For $\frac{m}{M} = 0.1$ and $v_b = 10$ m/s, find the first 6 sets of v and u velocities and graph them. What pattern do you observe?

d) Solve the problem again going through the above steps but this time assuming that a constant energy of E_b is released each time the cannon is fired.

e) How do the velocities obtained in part (d) differ from those in part (c)? How are the patterns different?