Theoretical Examination

The Physics Challenge

4 Problems
Duration: 3 Hours
Points: 35 Points

Advice: Take reference from anywhere (not human being) but solve every single problem!

Good Luck!

1 Hermoine and their Backyard Pool

[5 points]
Category: Geometrical Optics

Hermoine, the Hogwarts scholar, has a backyard swimming pool in their house. In the morning, when looking at the bottom of the pool, making an angle $\theta = 30°$ with the vertical, she estimated that the depth of the pool was $h = 8\,m$. Later, she came up with a meter stick in order to measure the depth. The water had a refractive index $\eta_w = 4/3 = 1.33$ and the refractive index of air is $\eta_a = 1$.
What is the actual depth of water in Hermoine's backyard Pool?
Include a diagram for credit.

2 Capacitors and breakdown Voltage

[10 points]
Category: Electric Circuitry

Capacitors are electric devices containing two conductors which is usually used to store electric energy. There is a critical voltage to be applied across the terminal of a capacitor, above which the capacitors break down, because the potential difference between two plates ionizes the dielectric medium in between, making them conducting. So, the capacitor cannot but discharge and lose all of its energy.

The breakdown voltage of all the capacitor used in this problem have the critical breakdown voltage $V_c = 20\,V$. The capacitance of each of the capacitors in our circuit are,

$$\begin{pmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{pmatrix} = \begin{pmatrix} 3\mu F \\ 8\mu F \\ 7\mu F \\ 10\mu F \end{pmatrix}$$

This simply means that $C_1 = 3\mu F$, $C_2 = 8\mu F$ and so on.

a. Capacitor C_1 and C_2 are connected in series. The capacitor C_3 is joined parallel to them. This system has two terminals, terminal a and c. **Draw this circuit**. Please label the diagram neat and appropiately for full credit.

b. Now another Capacitor of capacitance C_4, having terminals b and d is joined with the previous part. Terminal d is joined with terminal c. **Find the equivalent capacitance of the system**.

c. Appropriate potential difference has been applied across the terminals a and b so that no capacitor breaks down. **Find the maximum possible potential difference without ruining any capacitor.**

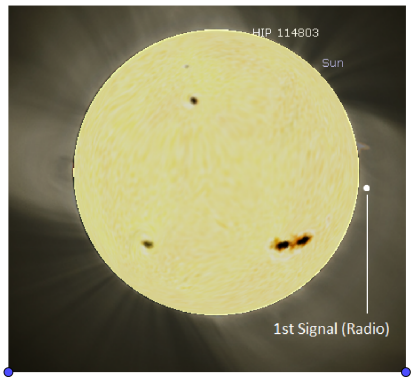
d. **What is the maximum energy that can be stored in the system?**

Point distribution: [1 + 2 + 4.5 + 2.5] points.

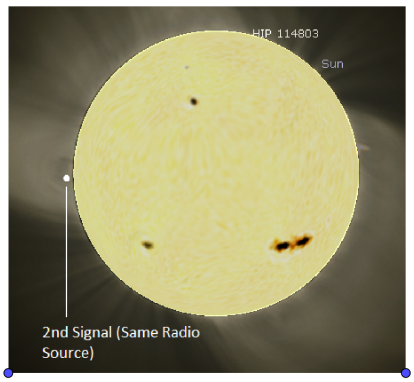
3 The Mysterious Radio Source

[10 points]
Category: Keplar's Law and Geometrical Astronomy

Cosmological Expansion causes the wavelength of space traveling light to increase. So an optical wavelength can turn to Microwave, or even Radio wave, depending on the situation. We term it Redshifting.
A strong Radio signal was received from an unknown source, by an Observatory in Equatorial zone dur-



Photograph 01 : *The* 1*st Signal*



Photograph 02 : *The* 2*nd Signal*

ing the Midday (12:00 pm), when the sun is exactly at the top; along the perpendicular line on the Earth surface. The first signal came as if it was to the Right side of Sun, as in Photograph 01. The redshifting measurements put forward that the source is $l_1 = 8.4692 \times 10^{11}\ m$ distance away.
Then the source was eclipsed by Sun. It means that, it went behind it.

Exactly $1\ month$ later, the same source made another signal. It came from the Left side as in Photograph 02, but this time the redshifting said that the distance of the source was $l_2 = 9.8241 \times 10^{11}\ m$, from Earth. This signal was received in the same Observatory as before, during Midday.

Assuming that the mysterious source moved in a straight line, what can be the average speed of the source? Does it have any possibility that it is orbiting the Sun?

Numerical Data:

- $r_{sun} = 6.690 \times 10^8 m$
- $d = 1 A.U = 1.490 \times 10^{11} m$
- T_{year} = 1 year = 12 months $\cong 3.14 \times 10^7 s \cong \pi \times 10^7 s$

Your solution must contain a diagram making illustration of the solution. Make a sketch that gives the idea about the trajectory (path taken by object) during the 1 month travel. Try to keep numerical values as exact as possible. Points for every correct detailing!

Supplimentary Astronomy Facts:

- The Earth orbit around the Sun is just Circular. And it is not a bad approximation either!
- $1\ A.U$ is 1 Astronomical Unit, that is the Semi Major Axis, or simply the Radius of the Earth orbit around the Sun.
- Suppose that $\sin\theta = x$. Now if it is that you want to find θ knowing the value of x, then, $\theta = \sin^{-1} x$. Your scientific calculator has this. For example, if you know that $\sin\theta = 0.5$, then $\theta = \sin^{-1}(0.5) = 30°$. Please be sure that your calculator is in Degree mode, not Radian.
- For a triangle with sides a, b, c, in case you know a, b and the angle θ between a, b, then the using the Cosine Formula,

$$c^2 = a^2 + b^2 + 2ab\cos\theta$$

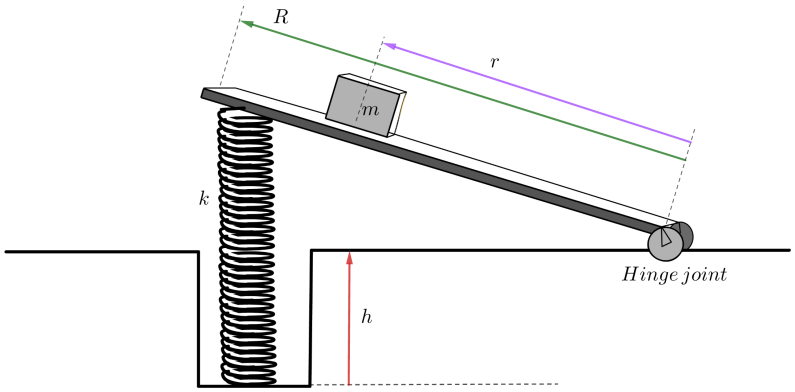
4 Throw the Mass!

[10 points]
Category: Mechanics

A thin, uniform rod of mass M and length R has it's one side pivoted friction-lessly on a point on ground and other side joined with a massless spring with spring constant k. The relaxed length of the spring is $h + L$(as in the figure, but the L has not been shown). A small mass m of negligible size is kept on the rod as shown.

The spring is compressed such that the rod is horizontal. The rod is then released. Assume that friction between mass m and the rod is enough that the mass doesn't slide. For simplicity, also assume that the force to the rod by the spring is always perpendicular to the rod.

The spring takes a circular arc shape (not depicted in the figure! Be careful!). Avoid any calculation for arc shape of Spring.



The numerical values are,

$$\begin{pmatrix} M \\ m \\ R \\ r \\ k \\ L \\ g \end{pmatrix} = \begin{pmatrix} 1\,kg \\ 2\,kg \\ 12\,m \\ 8\,m \\ 400\,N/m \\ 4\,m \\ 9.8m/s^2 \end{pmatrix}$$

a. Find the angle θ, what is the angle between rod and the horizontal, for which the mass m leaves the rod.

b. What is the horizontal and vertical distance covered by the mass m**?**

Points distribution: [4 + 6] points.