Physics for Pedestrians

Final examination

17th August, 2019

Maximum Marks: 60

Instructions:

- **Read the question paper carefully!**
- **No** electronic devices of any kind will be allowed during the examination.
- You are required to answer **SIX** questions in all. **Question 1 is compulsory**.
- Answer **FIVE** questions from Questions 2 to 10.
- Please answer all sub-parts of each question together.
- Make sure your answers are ***clear***. In case of derivations, each subsequent step should be clearly marked out. In long answers, your arguments should be lucid.
- Clearly state any assumptions you make when answering questions.

Useful constants and formulae

Constants

$c = 3 \times 10^8$ m/s	$R = 1.097 \times 10^7$ m^{-1}
$G = 6.67 \times 10^{-11}$ m^3/kg/s^2	Surface Tension of water, $s = 70 \times 10^{-3}$ kg/s^2
$h = 6.626 \times 10^{-34}$kg m^2/s	Density of air, $\rho_{\text{air}} = 1.225$ kg/m^3
$g = 10$ m/s^2	Density of water, $\rho_{\text{water}} = 10^3$ kg/m^3

Formulae

$\text{Density}(\rho) = \dfrac{\text{Mass}}{\text{Volume}}$	$F = ma$
Area of Circle $= \pi \times r^2$	$F_{12} = -F_{21}$
Volume of Sphere $= \dfrac{4}{3}\pi r^3$	Gravitational Force $= G\dfrac{m_1 m_2}{r^2}$
Lorentz Transformations:	Electrostatic Force $= K_e\dfrac{q_1 q_2}{r^2}$
$x' = \gamma\,(x - vt)$	Centripetal force $= \dfrac{mv^2}{r}$
$t' = \gamma\left(t - \dfrac{v}{c^2}x\right)$	Escape Velocity $= \sqrt{\dfrac{2GM}{R}}$
$\gamma = \dfrac{1}{\sqrt{1 - v^2/c^2}}$	Terminal velocity: $v_t = \sqrt{\dfrac{mg}{\rho_{\text{air}} A}}$

Potential Energy $= mgh$	Rydberg Formula: $\frac{1}{\lambda} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right)$
Kinetic Energy $= \frac{1}{2}mv^2$	Photoelectric Effect: K.E. $= hf - \phi$
Angular Momentum: $L = mvr$	De Broglie wavelength: $\lambda = \frac{h}{mv}$
Energy of a photon: $E = hf$	

ROUGH WORK

1 Compulsory (10 marks)

1. Find the dimensions of Newton's Gravitational constant G, Planck's constant h, and the speed of light c. Explain every step *clearly*. **(5 marks)**

2. Imagine that this room was stuffed with tennis balls:

   (a) Estimate the total number of tennis balls that could fit into this room. Estimate the total mass of all the balls together. **(3 marks)**

   (b) Now imagine that you started to fill the room with water that filled up all the cracks between the balls. Estimate the amount of water than could be poured into a room already full of tennis balls. Estimate the total mass of this water. **(2 marks)**

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2 Orders of Magnitude and Dimensions (10 marks)

1. Suppose you were shrunk by a factor of 10 in every direction, so that you became a tiny scale model of yourself. Describe the challenges you would face. Keep in mind your body temperature, the strength of your bones, your vision, and the difficulties posed by water, among other things. **(7 marks)**

2. The height h of a puddle of liquid on the surface of a planet depends on the density of the liquid ρ, the surface tension s of the liquid, and the acceleration due to gravity g. Find a formula for h using dimensional analysis. Taking the dimensionless constant to be of order 1, find h for water. **(3 marks)**

3 Estimation and Dimensions (10 marks)

1. Consider a roti, and imagine doubling its radius. Now determine how each of the following changes, along with any assumptions you make : (i) the total area of both its surfaces; (ii) the number of molecules of atta; (iii) the number of brown (burnt) spots on it. **(3 marks)**

2. According to the World Pool-Billiard Association: a pool ball is 2.25 inches in diameter and has a tolerance of +/- 0.005 inches. Is the Earth as smooth as a pool ball? **(3 marks)**

3. The area of an ellipse with axes a and b is given by one of the following formulas. Eliminate all the formulas that do not work, and identify the reasons why. **(2 marks)**

   (a) $\pi(a+b)$

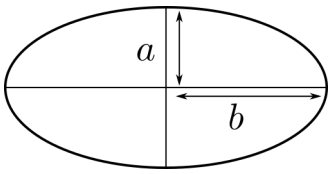
   (b) $\pi(a+b^2)$

   (c) $\pi(a^3/b)$

   (d) $\pi(a^2+b^2)$

   (e) πab

   (f) $2ab$



4. The fundamental natural frequency of oscillation f of a stretched string (for example on a guitar or violin) depends on its length l, its mass per unit length μ, and its tension Q. Tension has the same units as force. Use this information and dimensional analysis to find a formula for f. **(2 marks)**

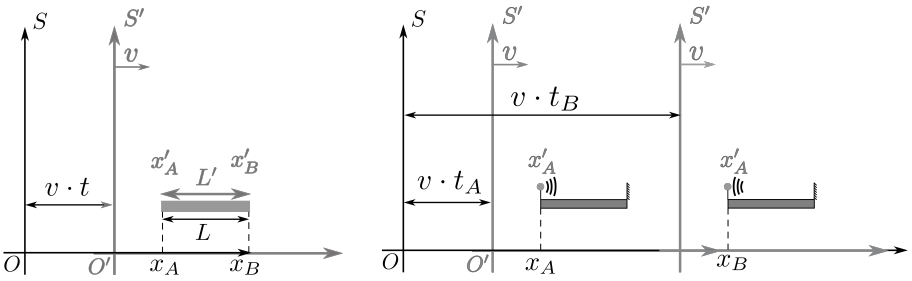
4 Newton's Laws (10 marks)

1. *Explain* Newton's three laws of motion.[1] Show that they provide us with a consistent framework with which to study the world. Make sure you mention the significance of their order, and the role played by each of the laws. **(5 marks)**

2. Using one of the three laws, show that a quantity called the *momentum* is conserved when two objects collide. Explain what it means for momentum to be "conserved". **(5 marks)**

5 Consequences of Special Relativity (10 marks)

Consider two observers, as explained in class, one of whom is in the frame S and the other who is in the frame S'. The frame S' is moving with a speed v with respect to the frame S.



(a) Lengths (b) Time Intervals

1. Show, using the Lorentz Transformations, that if an observer in S chooses to measure the length of an object moving with respect to her at a speed v (the object is thus at rest in S'), then this length L will be different from the length L' measured by an observer who is in S'. Make sure all your assumptions are stated *clearly*. **(4 marks)**

2. Consider a simple "light" clock that is at rest in S'. Show that the interval between emission and detection $\Delta t'$ measured by an observer in S' differs from the interval between the same two events Δt for an observer in S with respect to whom the clock is moving with a velocity v. Make sure all your assumptions are stated *clearly*. **(4 marks)**

3. In the last question, you have shown that the time-intervals will not be the same using a very simple light clock. However, what if you used an old grandfather clock, with many movable gears and internal parts? Can you think of an argument that will explain why the grandfather clock must also necessarily measure the same time dilation? **(2 marks)**

[1] Note that I did not say "State" Newton's Three Laws.

6 The Lorentz Transformations (10 marks)

1. Derive the Lorentz Transformations from first principles using desirable properties of space and time. Explain why our "common-sense" transformations seem "natural". **(10 marks)**

7 Waves and the Quantum World

1. Explain the results that you would expect if you conducted the double-slit experiment with:

   (a) Classical particles

   (b) Classical waves

   In the reading on Quantum Mechanics and Probability, how did Feynman describe the electrons as behaving in this experiment? Why was this puzzling? **(5 marks)**

2. Out of the three fundamental constants of Nature (G, c, and h), construct **(5 marks)**

   (a) A quantity of dimension length (call it l_p)

   (b) A quantity of dimension time (call it t_p)

   These are the Planck length and Planck time that we spoke of in the first lecture.

8 The Quantum Revolution (10 marks)

1. What were the problems with classical physics which were solved by the advent of Quantum Mechanics? Describe them in detail. **(5 marks)**

2. Describe the surprising results of the photoelectric effect that suggested that light was not a classical wave but was instead composed of small particles (called photons). **(5 marks)**

9 Gravity at Different Scales (10 marks)

1. How would explain that almost all substances that we know have densities between 1 g/cc and 10 g/cc? **(2 marks)**

2. How would you explain why planets are smoother and rounder than asteroids? **(2 marks)**

3. What are rotation curves? Show that the rotation curve for the planets in our solar system goes as

$$v \propto \frac{1}{\sqrt{r}}$$

   What do the rotation curves of galaxies tell us? How could these rotation curves be accounted for? **(3 marks)**

4. What are standard candles? Explain why they deserve their name, and how they show us that the universe is accelerating. What is now popularly thought to be the cause of this phenomenon? **(3 marks)**

10 Nightfall (10 marks)

1. Adam Roberts, writing the *History of Science Fiction* notes that in *Nightfall*, Asimov "collapses the Copernican revolution into a single night." Wouldn't it be more accurate to compare the events in the story to the discrepancies found with the orbits of Uranus and Mercury at the end of the 19^{th} century?

   Drawing from both the story and the course material, comment on this with special emphasis on the Copernican principle and the role that "intuition" plays in the development of scientific theories and in our understanding of the universe. **(10 marks)**

OR

2. The story *Nightfall* takes place in a period of anarchy on Lagash caused by the conflict between Rationalists and Cultists. Contrast the idea of Physical Law to Social and Religious Law. Drawing from different aspects of the course material, show how the notion of a Physical Law has changed from the time of Aristotle to the Quantum world. Compare this with notions of Social or Religious Law either from the story or human history. **(10 marks)**

ROUGH WORK