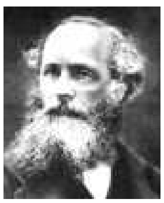
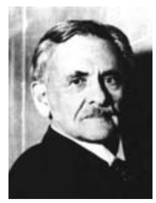
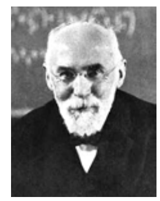
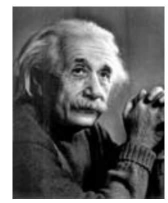
PHYS420 (Spring 2002)
Riq Parra

Exam #1
(Friday, March 1st, 2002)

# Exam 1 – Special Relativity

**Do NOT write your name on this exam. Write your class ID number on the top right hand corner of each problem page. Do NOT write your class ID number on this page.**

**Grading breakdown:**

| | |
|---|---|
| **Problem 1** | **35 points** |
| **Problem 2** | **40 points** |
| **Problem 3** | **20 points** |
| **Problem 4** | **20 points** |
| **Problem 5** | **20 points** |
| **------------------------------** | |
| **Total points** | **135 points** |

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**Problem 1 Short answer problem (35 points total – 5 points each)**

(1) What was the ether?

(2) Define an inertial reference frame.

(3) State Einstein's Postulates of Special Relativity.

(4) What is a **proper** time interval?

(5) A light source is known to emit light with a wavelength of 122 nm while at rest (in the ultraviolet region). While in motion, we observe the light to be Doppler shifted to 366 nm. Is the source approaching us or receding from us. Justify your answer.

(6) Sketch a graph of the Lorentz factor ($\gamma$) versus velocity (in units of $c$).

(7) In particle accelerators, electrons are accelerated to very high speeds. In a single graph, sketch the acquired electron velocity (in units of $c$) versus (a) the relativistic kinetic energy and (b) the non-relativistic kinetic energy.

**Problem 1 Extra Workspace.**

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**Problem 2 (40 points)**

Alpha Centauri, a nearby star in our galaxy, is 4.3 light-years away. This means that, as measured by a person on Earth, it would take light 4.3 years to reach this star. A rocket leaves for Alpha Centauri at a speed of $v = 0.95c$ relative to the Earth. Assume that the Earth and Alpha Centauri are stationary with respect to one another.

(a) Work out the distance to Alpha C., as measured by Earth observers, in km? *(5 points)*

(b) The distance calculated in (a), is it a proper distance? Justify your answer. *(5 points)*

(c) According to the astronauts, how much did they age (in years) during their journey? *(10 points)*

(d) According to the astronauts, how far (in km) did they travel? *(10 points)*

(e) One of the astronauts, using a meter stick, measures the length and diameter of the cylindrical spacecraft to be 82 and 21 m, respectively. Assuming that the spacecraft is oriented with its long cylindrical axis in the direction of motion, what are the dimensions of the spacecraft, as measured by an observer on earth? *(10 points)*

**Problem 2 Extra Workspace.**

**Problem 3 (20 points)**

A 20-year-old political prisoner named Bob is exiled to travel space for 35 Earth years. By a strange twist of fate, his daughter is born the very day that he leaves to serve his sentence. How fast would he need to travel so that, when he arrives back on Earth, he's the same age as his daughter?

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**Problem 4 (20 points)**

A physics professor claims in court that the reason he went through the red light ($\lambda$ = 650 nm) was that, due to his motion, the red color was Doppler shifted to green ($\lambda$= 550 nm). How fast was he going? *Useful reminder: The relation between frequency, f, and wavelength, λ, is given by* $c = \lambda f$ .

**Problem 5 (20 points)**

The particle accelerator at Stanford University is three kilometers long and accelerates electrons ( $m_{electron} = 9.11x10^{-31}\,kg$ ) to a speed of 0.999 999 999 7 c, which is very nearly equal to the speed of light.
(a) What is the rest energy (in **MeV**) of the electrons? *(1 eV = 1.602x10$^{-19}$ Joules)*
(b) Find the magnitude of the relativistic momentum of the electrons. Comparing it with the nonrelativistic value, is it bigger, smaller? By what factor?
(c) Compute the electron's total energy (in **GeV**).

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**Equation Sheet for Exam #1**
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**Lorentz Transformations**

$$\left\{\begin{array}{l} x' = \gamma(x - vt) \\ y' = y \\ z' = z \\ t' = \gamma(t - \frac{v}{c^2}x) \end{array}\right\} \text{ where } \gamma \equiv \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

**Velocity Transformation**

$$u'_x = \frac{u_x - v}{1 - \frac{u_x v}{c^2}}, \quad u'_y = \frac{1}{\gamma}\frac{u_y}{1 - \frac{u_x v}{c^2}}, \quad u'_z = \frac{1}{\gamma}\frac{u_z}{1 - \frac{u_x v}{c^2}}$$

**Time Dilation**

$$t = \gamma t_0 = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

**Length Contraction**

$$L = \frac{L_0}{\gamma} = L_0\sqrt{1-\frac{v^2}{c^2}}$$

**Doppler Shift**

$$f_{observer} = \frac{\sqrt{1+(v/c)}}{\sqrt{1-(v/c)}} f_{source}, \textit{ approaching source}$$

**Momentum**

$$p \equiv \frac{mu}{\sqrt{1-\frac{u^2}{c^2}}}$$

**Energy**

$$E_{total} = \frac{mc^2}{\sqrt{1-\frac{u^2}{c^2}}} = KE + E_{rest}; \qquad E_{rest} = mc^2$$

$$KE = \frac{mc^2}{\sqrt{1-\frac{u^2}{c^2}}} - mc^2 = E_{total} - E_{rest}; \qquad E_{total}^2 = p^2c^2 + (mc^2)^2$$