PHYS 2710: Modern Physics

Course Description

This course presents an introduction to our modern understanding of nature, which has been developed during the twentieth century. Topics include Einstein's special theory of relativity, the theory of quantum mechanics, wave-particle duality, the nature of atoms, and nuclear physics.

Prerequisites

PHYS 2220, MATH 1220 (minimum grades of C)

General Information

Class Times	SL 240, 9:00 AM M W F
Required Texts	Modern Physics for Scientists and Engineers, 2nd Ed. by Taylor et al.
Instructor	John Armstrong
Office Hours	SL 205, 2:00 - 4:00 PM, M; 9:00 - 10:00 AM, T Th, or by appointment
Email	jcarmstrong@weber.edu
Web	http://physics.weber.edu/armstrong
Phone	801.626.6215

Course Goals

Modern Physics is the study of the 'new' physics developed starting in the early 1900's to present (not to be confused with post-modern physics, which hasn't happened yet). This includes the Einstein and quantum revolutions and their applications to modern technology. For many of you, this is the first course where you get to stretch out and explore physics using all of the tools and skills gained in 2210/2220. Also, you will be learning about some amazing features of the Universe, and likely discover things don't work the way your intuition would lead you to believe. Throughout this course, you will develop problem solving skills that allow you to attack problems even when your intuition fails you.

Specifically, the course goals are:

- Examine the field of modern physics, with particular attention paid to current research topics.
- Develop your intuition using the principles of modern physics.
- Apply your experience in introductory physics to develop problem solving skills for more complex problems

Assignments

Weekly homework assignments will be assigned on Monday and due on the following Monday. These will largely be related to problems and assignments from your text, including some computational problems. Late assignments will be accepted for 48 hours after the deadline, depreciating linearly to 0 over that time period. Thus, homework worth 100% Monday at 9 AM is worth 50% Tuesday at 9 AM and worth 0% Wednesday at 9 AM.

Exams

There will be two in-class midterm exams and one comprehensive final exam.

Special Topics

Since this is the exploration of modern physics, the last two weeks of class are reserved for special topics that will be presented by you, the students. You can select any topic not previously covered in the class that interests you (in or out of the textbook), provided it is related to modern physics. You will research the topic and present a 10-minute in-class summary along with a final paper you will hand in at the end of class. Details of this project will follow as we get closer to the end of the course, but keep your eyes open for articles or other items of interest you might want to explore in detail.

Grading Policy

You grade will be compiled from homework, the project, and exams according to the following:

Assignments	50%
Topics Project	15%
Midterms (2 x 10%)	20%
Final Exam	20%

Attendance Policy

While I will not be taking attendance in class, you are encouraged to attend regularly. This is going to be an awesome, exciting class, so why would you want to be anywhere else?

Academic Integrity

Regarding academic integrity, I will enforce policies as laid down in Section IV:D of the Student Responsibilities outlined in the Student Code. Specifically, no cheating or other forms of academic dishonesty will be tolerated. The first instance of cheating will result in a zero on that assignment. The second instance will result in failing the class. You will be working in groups occasionally, however, so you will be required to distinguish the difference between collaboration and cheating. When in doubt, make sure to give credit where credit is due.

Expectations and Responsibilities

I want to stress upfront that this is a quantitative science course. With that in mind, we will be doing some math. Some of your assignments will require you to employ some mathematical skills, which I will help you refresh/acquire in this course. I expect you to give yourself adequate time to complete the assignments and to put a good faith effort into all of your collaborative work. You should expect me to provide you with as much support as humanly possible, including technical/psychological math support and general sympathy. That said, starting the assignment on the day it is due is an excellent way to dissolve the sympathy part! If you give me enough lead time to help, I will make sure you get it. My office hours are posted, and I can be available at other times if necessary. I am here to make sure you get as much out of this course as you possibly can.

Special Accommodations

Any students requiring accommodations or services due to a disability must contact Services for Students with Disabilities (SSD) in room 181 of the Student Service Center. SSD can also arrange to provide course materials (including this syllabus) in alternative formats if necessary.

Schedule (Subject to Change)

Week of...	Monday	Wednesday	Friday	Reading
Jan 8	Introduction	Special Relativity	Time Dilation/Length Contraction	1.1-1.10
Jan 15	MLK Day	Lorentz Transformations	The Doppler Effect	1.11-1.14
Jan 22	Relativistic mass and momentum	Relativistic energy	Mass/Energy Conversion	2.1-2.6
Jan 29	Force and Massless Particles	General Relativity	The Twin Paradox	2.7-2.10
Feb 5	Elements, atoms, and particles	Exam Review	Exam I	3.1-3.4
Feb 12	Kinetic Theory	Mean free path and Brownian motion	Quantization	3.5-4.3
Feb 19	Presidents' Day	X-ray diffraction/ Compton scattering	Wave-Particle Duality	4.5-4.7
Feb 26	Atomic Spectra	The Bohr atomic model	Hydrogen-like ions	5.1-5.9
March 5	Matter Waves	The Quantum wave function	The Uncertainty Principle	6.1-6.9
March 12		Spring Break		
March 19	The Schrödinger Equation in 1-D	Particle in a Box	The Simple Harmonic Oscillator	7.1-7.9
March 26	The Schrödinger Equation in 3-D	Quantized Angular Momentum	The Hydrogen Atom	8.1-8.10
April 2	Electron Spin	Exam Review	Exam II	9.1-9.6
April 9	Pauli Exclusion Principle	Ground State of Elements	The Periodic Table	10.1-10.8
April 16	Topics			
April 23	Topics			
April 30		Finals Week		

Typical Assignments

Assignments are assigned on Wednesday, due the following Wednesday, except for exams and project weeks. All assignments are out of "Modern Physics For Scientists and Engineers" by Taylor, et al.

Topic	Assignment
Relativity and Time Dilation	1.1, 1.4, 1.12, 1.21, 1.24, 1.26
Length Contraction and Lorentz Transformations	1.35, 1.36, 1.42, 1.45, 1.48, 1.49
Relativistic Motion and Energy Conversion	2.1, 2.5, 2.7, 2.13, 2.24, 2.25, 2.32
Relativistic Force and Massless Particles	2.34, 2.35, 2.38, 2.41, 2.42, 2.46
Exam	
Atomic Properties and Kinetic Theory	3.12, 3.25, 3.28, 3.30, 3.40, 3.45
Quantization of Light	4.1, 4.4, 4.16, 4.18, 4.32, 4.33
Quantization of Atomic Energy Levels	5.6, 5.7, 5.10, 5.14, 5.19
Matter Waves	6.9, 6.17, 6.31, 6.35, 6.42, 6.44
Exam	
The Schrödinger Equation in 1-D	7.4, 7.13, 7.20, 7.26, 7.53
The Schrödinger Equation in 2-D	8.5, 8.9, 8.11, 8.16, 8.18, 8.24
The Schrödinger Equation in 3-D	8.38, 8.39, 8.46, 9.6, 9.7, 9.8
Projects	
Projects	
Finals	

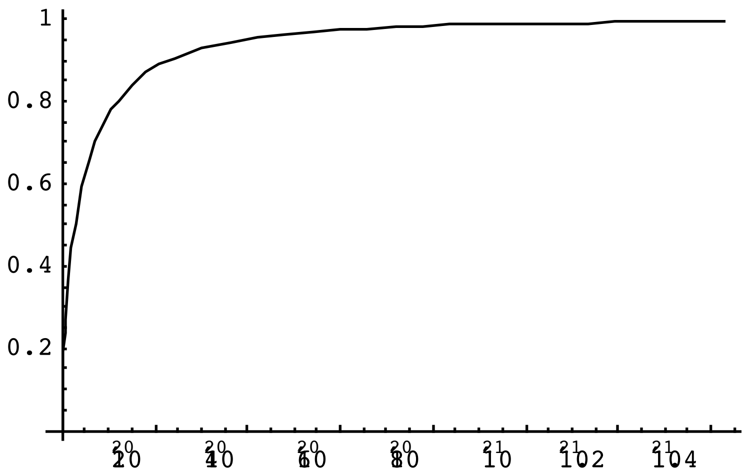
Modern Physics Mathematica Assignment #1 - Solutions

Relativistic Space Travel

Imagine you are in charge of sending a 2000 kg robotic space probe to the nearest star as part of Earth's first attempt at interstellar exploration. If we contrive to apply a constant force to the probe (say, using a sweet new anti-matter drive), we could accelerate it to near the speed of light by increasing the kinetic energy without limit.

1. Make a plot of the velocity of the probe as a function of its kinetic energy.

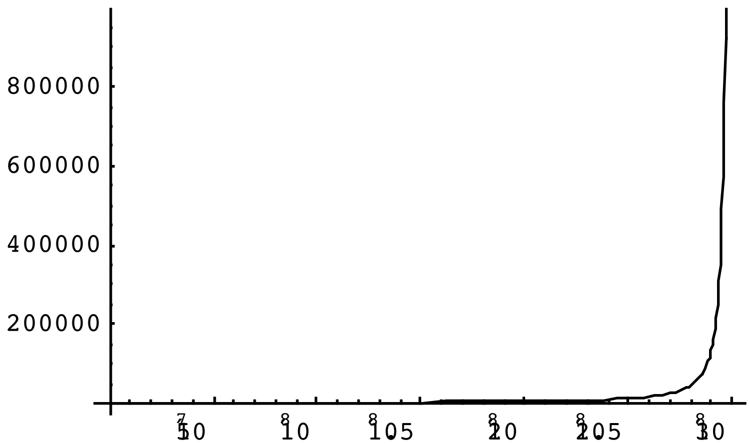
```
c = 2.99 × 10^8;   (* The speed of light *)
m = 2000;          (* The mass of the ship *)
β = u/c;
γ = 1/Sqrt[1 - β^2];

velocity = Sqrt[1 - (m c^2/(K + m c^2))^2];

Plot[velocity, {K, 0, 8 m c^2}]
```




```
- Graphics -
```

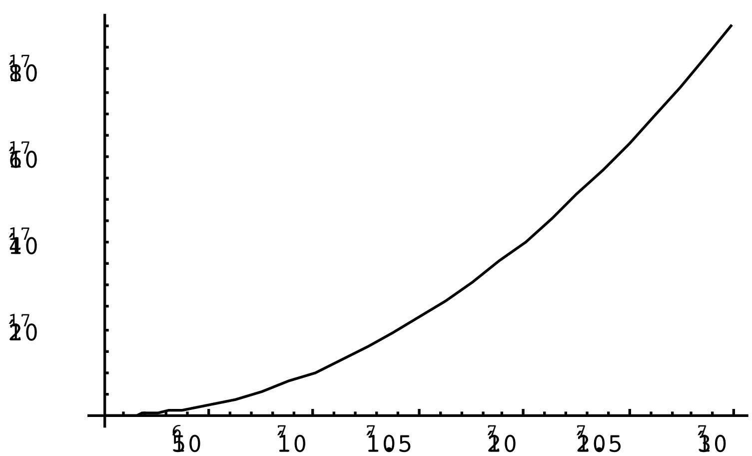
2. Make a plot of the force that must be exerted on this probe as a function of the probe's velocity. Hin

```
momentum[u_] = γ m u;
force[u_] = momentum'[u];
Plot[force[u], {u, 0, c}];
```



3. How much energy is required to take the spacecraft from 0 to 0.1 c? From 0.1 to 0.9 c? From 0.9 to (

```
kinetic = (γ - 1) m c²;
Plot[kinetic, {u, 0, 0.1 c}]
Plot[kinetic, {u, 0.1 c, 0.9 c}]
Plot[kinetic, {u, 0.9 c, 0.99 c}]
Plot[kinetic, {u, 0.99 c, 0.999 c}]
```



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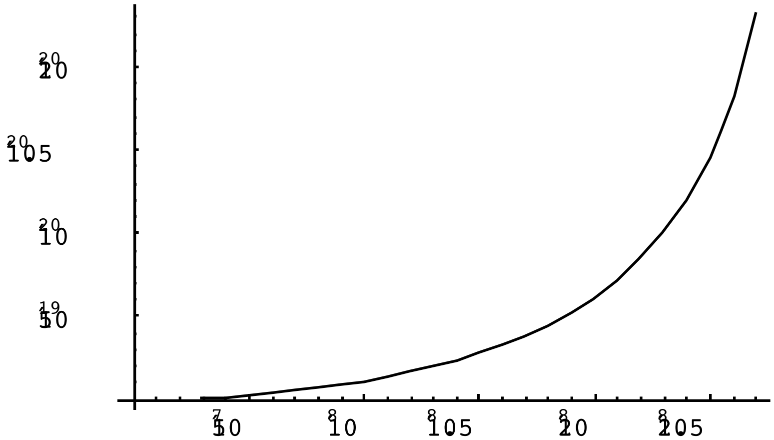

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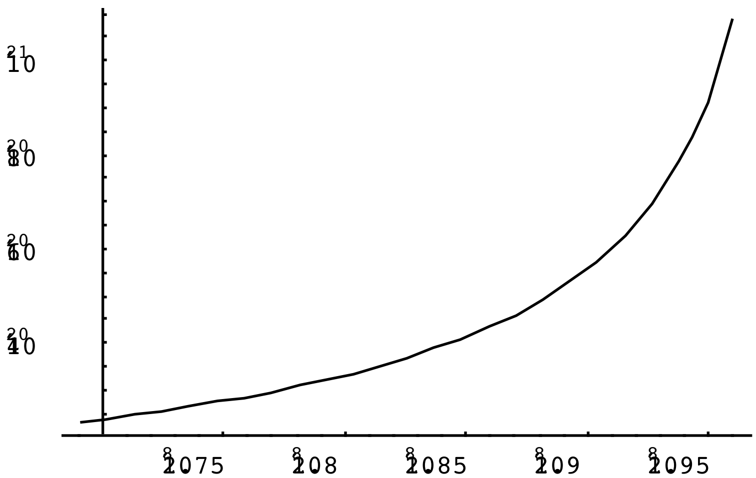

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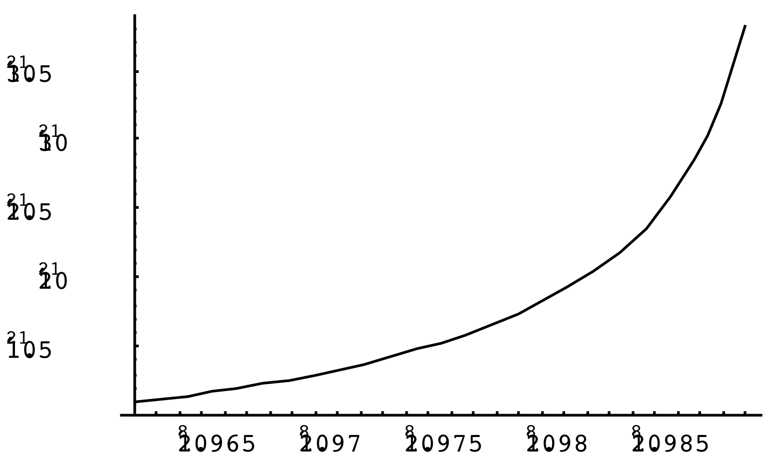

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4. Compare these energies to a hypothetical anti–matter energy drive that converts positrons and elec

```
mass = 9.1 × 10^-31;           (* Mass of an electron, in kg *)
energySource = mass c^2;
numberOfReactions1 = (9 × 10^17 - 0)/energySource;
totalFuel1 = numberOfReactions1/2 × mass;
Print["Total mass required for 0.0 to 0.1 c: ", totalFuel1, " kg"]
numberOfReactions2 = (3.0 × 10^20 - 1 × 10^19)/energySource;
totalFuel2 = numberOfReactions2/2 × mass ;
Print["Total mass required for 0.1 to 0.9 c: ", totalFuel2, " kg"]
numberOfReactions3 = (2 × 10^21 - 1 × 10^20)/energySource;
totalFuel3 = numberOfReactions3/2 × mass;
Print["Total mass required for 0.9 to 0.99 c: ", totalFuel3, " kg"]
numberOfReactions4 = (3.5 × 10^21 - 1.5 × 10^21)/energySource;
totalFuel4 = numberOfReactions4/2 × mass;
Print["Total mass required for 0.99 to 0.999 c: ", totalFuel4,
  " kg"]
```

```
Total mass required for 0.0 to 0.1 c: 5.0335 kg
Total mass required for 0.1 to 0.9 c: 1621.91 kg
Total mass required for 0.9 to 0.99 c: 10 626.3 kg
Total mass required for 0.99 to 0.999 c: 11 185.6 kg
```

Above, it requires 5 kg of fuel to go from 0 to 0.1 c, an additional 1600 kg (nearly the mass of the ship!!

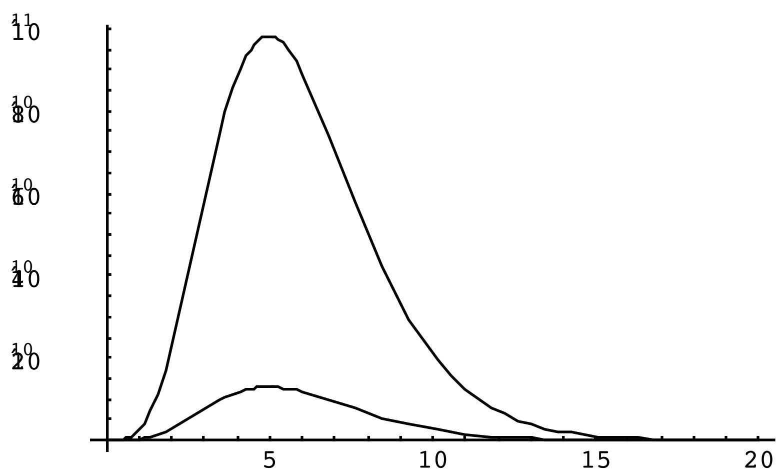
Assignment #5 Solutions

Problem 4.32

Make plots of the Planck function for T = 1000 and T = 1500 K. Comment.

```
c = 2.99 × 10^8;
h = 6.63 × 10^-34;
k = 1.38 × 10^-23;
σ = 5.67 × 10^-8;

const[T_] = 2 π (k T)^5 / (h^4 c^3);
intensity[x_, T_] = const[T] x^5 1/(e^x - 1);
power[T_] = σ T^4;
Plot[{intensity[x, 1500], intensity[x, 1000]}, {x, 0.1, 20}]
power[1500] / power[1000]
```




```
- Graphics -
```

```
5.0625
```

In the above plot, the 1500 K blackbody has a peak that is shifted to higher energies (larger values of x), and the total power is approximately 5 times *greater than the 1000 K blackbody.*

Problem 4.33

Determine the relationship between temperature and the wavelength of the maximum value of the blackbody spectrum. Do this by taking the derivative of the Planck function, setting it equal to 0, and solving for x.

$$\text{intensity2}[x\_] = x^5 \frac{1}{e^x - 1};$$

```
deriv[x_] = intensity2'[x]
NSolve[deriv[x] == 0, x]
```

$$\frac{5\, x^4}{-1 + e^x} - \frac{e^x\, x^5}{(-1 + e^x)^2}$$

```
{{x → 4.96511}}
```

$$\text{weinConstant} = \frac{h\, c}{k\, 4.96511}$$

```
0.00289319
```

The value above is the constant you get if you multiply the temperature in Kelvin by the wavelength in meters. Thus, the wavelength and the temperature are inversely proportional...the hotter the object, the bluer the peak wavelength.

Note: I dropped the constants in my equation for the intensity because they dropo out when I set the derivative equal to 0 and solve for x.

Review Exam I - PHYS 2710

This exam will cover chapters 1 and 2 in your text, including (but not limited to) the following topics:

1. Special Relativity
2. Time dilation
3. Length contraction
4. Lorentz transformations
5. Doppler shift
6. Mass, energy, momentum, and force in relativity
7. Conversion of mass to energy
8. Massless particles
9. General relativity

Some study tips:

1. Start by reviewing your homework and look for places where you have questions. Then, talk to me about things you don't understand prior to the exam.
2. Focus on materials that have been emphasized more than once.
3. Ask questions!! By email, office visit, whatever. I'll be happy to help.

Name________________________________

Exam One

Physics 2710 Spring 2007
Armstrong

This is Exam I for Modern Physics. Each question is worth in points indicated. It is closed book, closed note, except for one 3x5 note card. Please record all answers on the sheets provided, and show all of your work for full credit. Good Luck and have fun!

1. (20 points)

   (a) Prove that Newton's second law ($F = ma$) is invariant between the lab frame S to the moving inertial frame S' in classical physics.

   (b) Show that the definition of force ($\mathbf{F} = \frac{d\mathbf{p}}{dt}$) invalidates Newton's second law for any generic force acting on an object traveling at a relativistic speed.

2. (20 points)

   (a) What are the two principles of Special Relativity?

   (b) What additional principle is required to make this theory "general"?

   (c) What fundamental assumption was made about the properties of matter in Einstein's Equivalence Principle?

   (d) Describe one experiment that validates Einstein's theory of General Relativity.

3. (20 points) Consider a 100 cm relativistic snake (go on, we'll wait) traveling at a speed of 0.6 c. A mischievous boy holds two hatchets 80 cm apart and drops them simultaneously. Use the Lorentz transformations to find the positions and times of the two hatchets as measured by the snake to verify that the snake is unharmed if relativity is correct. What happens to the snake if relativity is wrong?

4. (20 points) As seen from the rest frame of the Earth (frame S) two rockets A and B are approaching from opposite directions, each with a speed of 0.9 c relative to S. Find the velocity of rocket B as measured by the pilot of rocket A.

5. (20 points) Consider the decay reaction:

$$M \rightarrow m_1 + m_2 \tag{1}$$

where M is at rest, and m_1 and m_2 shoot off in opposite directions.

(a) Is the mass of M greater than, less than or equal to $m_1 + m_2$. How do you know?

(b) Assuming $m_1 = 0.5\ GeV/c^2$, $m_2 = 1.0\ GeV/c^2$, and the momentum of m_1, $p_1 = 2.0\ GeV/c$, compute the original mass of the particle M. Express your answer in GeV/c^2.

(c) How much energy was liberated in this reaction (express in GeV)?

Equation Sheet

Physics 2710 Spring 2006
Armstrong

$$
\begin{aligned}
\beta &= \frac{u}{c} = \frac{pc}{E} \\
\gamma &= \frac{1}{\sqrt{1-\beta^2}} \\
\Delta t &= \gamma \Delta t_0 \\
l &= \frac{l_0}{\gamma}
\end{aligned}
$$

$$
\begin{aligned}
x' &= \gamma\left(x - vt\right) \\
y' &= y \\
z' &= z \\
t' &= \gamma\left(t - \frac{vx}{c^2}\right)
\end{aligned}
$$

$$
\begin{aligned}
u'_x &= \frac{u_x - v}{1 - \frac{u_x v}{c^2}} \\
u'_y &= \frac{u_y}{\gamma\left(1 - \frac{u_x v}{c^2}\right)} \\
u'_z &= \frac{u_z}{\gamma\left(1 - \frac{u_x v}{c^2}\right)}
\end{aligned}
$$

$$
\begin{aligned}
f_{obs} &= \sqrt{\frac{1+\beta}{1-\beta}} \;\; blueshift \\
f_{obs} &= \sqrt{\frac{1-\beta}{1+\beta}} \;\; redshift
\end{aligned}
$$

$$
\begin{aligned}
p &= \gamma m u \\
E &= \gamma m c^2 \\
E &= mc^2 + K \\
E &= \sqrt{(pc)^2 + (mc^2)^2} \\
K &= (\gamma - 1)\, mc^2 \\
F &= \frac{dp}{dt}
\end{aligned}
$$

Review Exam II - PHYS 2710

This exam will cover chapters 3-8 in your text, including (but not limited to) the following topics:

1. Atomic Theory
2. Quantization
3. Photoelectric effect
4. Bohr atom
5. Wave-particle duality
6. Wave functions
7. Uncertainty principle
8. Schrödinger equation in 1-, 2-, and 3-D

Some study tips:

1. Start by reviewing your homework and look for places where you have questions. Then, talk to me about things you don't understand prior to the exam.
2. Focus on materials that have been emphasized more than once.
3. Ask questions!! By email, office visit, whatever. I'll be happy to help.

Equation Sheet

Physics 2710 Spring 2006
Armstrong

$$\beta = \frac{u}{c} = \frac{pc}{E}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

$$\Delta t = \gamma \Delta t_0$$

$$l = \frac{l_0}{\gamma}$$

$$f_{obs} = \sqrt{\frac{1+\beta}{1-\beta}} \quad blueshift$$

$$f_{obs} = \sqrt{\frac{1-\beta}{1+\beta}} \quad redshift$$

$$p = \gamma m u$$

$$E = \gamma m c^2$$

$$E = mc^2 + K$$

$$E = \sqrt{(pc)^2 + (mc^2)^2}$$

$$K = (\gamma - 1)\, mc^2$$

$$F = \frac{dp}{dt}$$

$$PV = nRT$$

$$E = hf = \hbar\omega$$

$$p = \frac{h}{\lambda} = \hbar k$$

$$\Delta x \Delta p = \frac{\hbar}{2}$$

$$P\,(a < x < b) = \int_a^b |\psi(x)|^2 dx$$

$$L = \sqrt{l(l+1)}\hbar$$

$$L_z = m\hbar$$

Name____

Exam Two

Physics 2710 Spring 2007
Armstrong

This is Exam II for Modern Physics. Each question is worth the points indicated. It is closed book, closed note, except for one 3x5 notecard. Please record all answers on the sheets provided, and show all of your work for full credit. Good Luck and have fun!

1. (25 points) The 1-D time independent Schrödinger Equation,

$$\frac{d^2\psi}{dx^2} = \frac{2M}{\hbar^2}\left[U\left(x\right) - E\right]\psi \tag{1}$$

allows us to determine the wave function for a given system.

(a) In general terms, what *is* a matter wave function?

(b) What does the matter wave function tell us?

(c) List the steps require to solve the Schrödinger Equation for a given system. That is, what do you need to know, what steps do you need to take, what are you trying to find out?

2. (25 points) For the infinite square well (of width a), the potential energy is $U(x) = 0$ inside the well and $U(x) = \infty$ outside the well. In this case, the general solution to Eq. (1) is:

$$\psi(x) = Asin(kx) + Bcos(kx) \tag{2}$$

List the proper boundary conditions for the infinite square well, show that the specific solution is $\psi(x) = Asin(kx)$, demonstrate that $k = n\pi/a$ and that the normalization constant $A = \sqrt{2/a}$. (hint: $\int sin^2(kx)dx = \frac{x}{2} - \frac{sin(2kx)}{4k}$).

3. (25 points) For the infinite square well of the last problem, what is the probability of finding the particle between $x = 0.49a$ and $x = 0.51a$ in the $n = 1$ state? In the $n = 3$ state?

4. (25 points) You are sitting in your lawn chair one summer day, playing with your new GPS receiver in preparation for a big hiking trip. Suddenly, you remember the uncertainty principle from modern physics class, and get a little worried that your own quantum nature will get you lost next time you are in the woods!

   (a) Assuming your GPS has an accuracy of 1 meter, determine the uncertainty in your momentum.

   (b) What is the corresponding uncertainty in your velocity (state your assumptions)?

   (c) At this speed, how far will you move over the age of the Universe (13 billion years)?

   (d) Are you still worried that your quantum 'uncertainty' will ruin your backpacking trip?

Review Exam Final - PHYS 2710

This exam will cover the entire class, including (but not limited to) the following topics:

1. Special Relativity
2. Time dilation
3. Length contraction
4. Lorentz transformations
5. Mass, energy, momentum, and force in relativity
6. Conversion of mass to energy
7. Massless particles
8. General relativity
9. Quantization
10. Bohr atom
11. Wave-particle duality
12. Wave functions
13. Uncertainty principle
14. Schrödinger equation in 1-, 2-, and 3-D
15. The Hydrogen Atom
16. Spin
17. Student Projects

Some study tips:

1. Start by reviewing your homework and look for places where you have questions. Then, talk to me about things you don't understand prior to the exam.
2. Focus on materials that have been emphasized more than once.
3. Ask questions!! By email, office visit, whatever. I'll be happy to help.

Name ____________________

Final Exam

Physics 2710
Armstrong

Spring 2007

This is the Final Exam for Modern Physics. Each question is worth the points indicated. It is closed book, closed note, except for the equations sheet provided. Please record all answers on the sheets provided, and show all of your work for full credit. Good Luck and have fun!

1. (20 points) In a certain experiment, a balloon carries a muon detector to an altitude of 1500 meters. After one hour, the detector records 700 muons with a speed of $0.99c$ traveling toward the earth. If an identical detector remains at sea level, how many muons would you expect it to register in one hour? Recall that the proper half-life of a muon is about 1.5 μs and that, after n half-lifes, the number of muons surviving from an initial sample N_0 is $N_0/2^n$.

2. (20 points) A subatomic particle A decays into two identical particles B:

$$A \rightarrow B + B \tag{1}$$

and it is observed that both particles, B, have the same momentum in opposite directions with magnitude p. What can you deduce about the velocity of the original particle A? Derive and expression for the mass, m_A, of A in terms of m_B and p.

3. (20 points) Consider a *2-D infinite square well* with sides of length a. The 2-D time-independent Schrödinger for this case is:

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = \frac{2M}{\hbar^2}[U - E]\psi \tag{2}$$

Using separation of variables, find $\psi(x, y)$ and the energy levels in terms of the quantum numbers n_x and n_y. Also, write down the proper formula used to determine the normalization constant (you do not need to solve for it).

4. (20 points) Describe, in words, the meaning of the quantum numbers n, l, m, s, and m_s. What are the possible limits of these quantum numbers for the hydrogen atom? Demonstrate that the degeneracy for any level n, when spin is accounted for, is $2n^2$.

5. (10 points) Questions from student projects:

   (a) What part of the sun is responsible for the emission of solar neutrinos?

   (b) What is the size of a nano-tube?

   (c) The wavelength of light emitted from a quantum dot depends on its...

   (d) Is it possible to travel to distant stars in a human lifetime?

   (e) What quantum effect causes the voltage leakage in computer processors?

   (f) What is the quantum effect that holds up white dwarfs against gravitational collapse?

   (g) What property of the hydrogen atom is probed through Magnetic Resonance Imaging?

Equation Sheet

Physics 2710 Spring 2006
Armstrong

$$\begin{aligned}
\beta &= \frac{u}{c} = \frac{pc}{E} \\
\gamma &= \frac{1}{\sqrt{1-\beta^2}} \\
\Delta t &= \gamma \Delta t_0 \\
l &= \frac{l_0}{\gamma}
\end{aligned}$$

$$\begin{aligned}
x' &= \gamma\left(x - vt\right) \\
y' &= y \\
z' &= z \\
t' &= \gamma\left(t - \frac{vx}{c^2}\right)
\end{aligned}$$

$$\begin{aligned}
u'_x &= \frac{u_x - v}{1 - \frac{u_x v}{c^2}} \\
u'_y &= \frac{u_y}{\gamma\left(1 - \frac{u_x v}{c^2}\right)} \\
u'_z &= \frac{u_z}{\gamma\left(1 - \frac{u_x v}{c^2}\right)}
\end{aligned}$$

$$\begin{aligned}
p &= \gamma m u \\
E &= \gamma m c^2 \\
E &= mc^2 + K \\
E &= \sqrt{(pc)^2 + (mc^2)^2} \\
K &= (\gamma - 1)\, mc^2 \\
F &= \frac{dp}{dt} \\
PV &= nRT \\
E &= hf = \hbar\omega \\
p &= \frac{h}{\lambda} = \hbar k \\
\Delta x \Delta p &= \frac{\hbar}{2} \\
P\left(a < x < b\right) &= \int_a^b |\psi(x)|^2 dx \\
L &= \sqrt{l(l+1)}\hbar \\
L_z &= m\hbar \\
S &= \sqrt{s(s+1))}\hbar \\
S_z &= m_s\hbar
\end{aligned}$$

Summary of Topics Project
Topics Start on April 16

The topics talks have the following goals:

1. Allow us to cover topics not discussed in detail in class
2. Provide an opportunity to explore actual modern physics at work
3. See (from others' projects) the wealth of material we've missed in class lectures
4. Have fun!

1 Expectations

The topics for this project are completely up to you, but you should connect your discussion to topics in modern physics. The question you are trying to answer is "how do we know what we know". Use that to frame your presentation. That said, you will only have about 15 minutes (including a little time for a question or two) to present your material. If it makes you feel better, this is the exact same amount of time presenters get at the American Astronomical Society meeting. Your talk should:

1. Have no more than five slides (powerpoint or otherwise) to use during your talk
2. Briefly (and succinctly) outline the issue you are discussing
3. Showcase the topic, or a subset of the topic

Remember, you only have 15 minutes, so if you can't explain your entire topic in that amount of time, talk about a subset of your topic. For example, if you can't talk about 'quantum mechanics' in ten minutes, choose to talk about the Stern-Gerlach experiment. In fact, in many cases, it helps to focus on a single experiment. If you have a problem identifying a reasonable subset, talk to me.

The project is worth 15% of your grade, and will evaluated using the following criteria:

1. Your grasp of the content you are presenting
2. How well the content is matched to the presentation time allowed
3. How well you connect your discussion to "how we know what we know"

On Friday, April 27th, please hand in copies of your slides and a written summary of your presentation topic (no more than three pages single spaced).