Today – Exam#2 Review

- Exam #2 is Thursday March 13 in this room, BPS 1410
- Extra Credit Projects: Spring Break Story Contest
- The exam is 40 multiple choice questions. There are a few questions where you will have to use a formula and calculator.
- Bring your student ID
- You will have the full 80 minutes for the exam.
- You can bring one 8.5x11 inch sheet of notes (front and back)
Where are we?

- There are 4 known forces in nature (Gravity, weak, EM- electromagnetic, strong)
- Gravity does not fit well in our understanding with the others
  - It is very weak compared to the others. Why?
- Our understanding of force involves the exchange of force carrying bosons between particles
The particles of nature

<table>
<thead>
<tr>
<th>Charge</th>
<th>1st gen.</th>
<th>2nd gen.</th>
<th>3rd gen.</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2/3</td>
<td>u (up)</td>
<td>c (charm)</td>
<td>t (top)</td>
</tr>
<tr>
<td>-1/3</td>
<td>d (down)</td>
<td>s (strange)</td>
<td>b (bottom)</td>
</tr>
<tr>
<td>0</td>
<td>(\nu_e) (e neutrino)</td>
<td>(\nu_\mu) ((\mu) neutrino)</td>
<td>(\nu_\tau) ((\tau) neutrino)</td>
</tr>
<tr>
<td>-1</td>
<td>e (electron)</td>
<td>(\nu_\mu) ((\mu) neutrino)</td>
<td>(\nu_\tau) ((\tau) neutrino)</td>
</tr>
</tbody>
</table>

Overlapping the table are labels indicating charge for quarks and leptons, and a separate section for gauge particles including strong, electromagnetic, and weak forces.

- Anti-particles have opposite charge.
How nature is put together from the pieces...

Atoms

Made of nuclei and electrons. Size: $10^{-9} m$

Atomic Nucleus

Made of neutrons and proton. Size $10^{-14} m$

A proton (uud)

Made of quarks: Size $10^{-15} m$
A neutron has ddu
Closer to what a proton really looks like

http://www.gwu.edu/~cns/theory/theory_webpage/proton2_qcd.jpg
# A summary of the forces of nature

<table>
<thead>
<tr>
<th>Force</th>
<th>Strength</th>
<th>Carrier</th>
<th>Acts on</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>1</td>
<td>Gluon, g</td>
<td>quarks</td>
<td>$10^{-15}$ size of a proton</td>
</tr>
<tr>
<td>Electromagnetic</td>
<td>1/137</td>
<td>photon</td>
<td>anything with charge</td>
<td>infinite</td>
</tr>
<tr>
<td>Weak</td>
<td>$10^{-6}$</td>
<td>Vector Bosons $W^+, W^-, Z^0$</td>
<td>quarks, electrons (leptons), neutrinos</td>
<td>$10^{-18}$ Only 0.001 width of proton</td>
</tr>
<tr>
<td>Gravity</td>
<td>$6x10^{-39}$</td>
<td>Graviton (?)</td>
<td>anything with mass</td>
<td>infinite</td>
</tr>
</tbody>
</table>
Our Picture of Force

A charge creates a field...

\[ \Delta E \Delta t \geq \frac{h}{4\pi} \]

Virtual particles can exist for a short time.

ISP209s7 Exam2 Review
Why is the sky blue? Feynman Diagram

The process is more likely if the photon energy is higher. Hence blue light scatters more than red light.
Coulomb's Law

- Charge comes in units of $1.6 \times 10^{-19}$ C.

- The force between two charges is:

$$ F = \frac{kq_1q_2}{r_{12}^2}; \quad k = 8.99 \times 10^9 \frac{Nm^2}{C^2} $$

- Example (inverse square law): 4 times the distance

$$ F'_{4d} = \frac{kq_1q_2}{(4r_{12})^2} = \frac{1}{4^2} \frac{kq_1q_2}{r_{12}^2} = \frac{1}{16} \frac{kq_1q_2}{r_{12}^2} = \frac{1}{16} F_d $$
The Earth behaves as a large magnet

The Earth is like a large magnet with a south magnetic pole at the North geographic pole.

T/F  A-true B-false
• T North pole of a compass points north in northern hemisphere
• F North pole of a compass points south in southern hemisphere
• T North pole of a compass points towards the north in the southern hemisphere
Map for the Electric Field

Note: we could make similar maps for all the fields in nature (gravity, weak, EM, strong).
The relation between electric and magnetic fields

- Charge creates an electric field (and potential, $V$)
- Moving charge creates a magnetic field
- The photon is responsible for transmitting both the electric and the magnetic forces
- Maxwell’s equations describe the relationship
  - Charge makes electric fields
  - Changing magnetic field makes electric fields
  - Changing electric fields make magnetic fields
  - Magnets always come with a north and a south pole
  - EM waves travel at the speed of light (in a vacuum)
Sample Problem

What is the magnitude of the electric field at 2.0 m?

\[
E = - \frac{\Delta V}{\Delta x} = - \frac{(0V - 80V)}{(4m - 0m)} = 20.0 \frac{V}{m} = 20.0 \frac{N}{C}
\]
Sample Problem

Electric field is the rate of change of potential with position.
Simple Problem

\[ F = E \cdot q \]

If a charge of 1.5 C is placed on an electric field of 15.5 V/m, what is the magnitude of the force on the charge?

Answer:
\[ F = 15.5 \text{ N/C} \times 1.5 \text{ C} = 23.3 \text{ N} \]
Batteries are like pumps that lift charge to a higher potential. The charge flows down the hill to the other side of the battery.
Energy, Work, etc.

- Two kinds of energy: Kinetic – energy of motion, Potential – energy of position
- Energy is measured in Joules, J
- Power = Energy/time. The unit is Watts = J/s
- Energy is always conserved. Energy conservation can be used to find how high something will go.
- Work = force x distance, converts energy from one form to another.
Chemical Energy

• 1 Calorie = 4184 J

• How many Calories are used by a person to lift 200 kg 1 m? Assume people are 10% efficient in converting chemical energy to work.

\[ \text{Work} = mgh = 200 \times 9.81 \times 1 = 1962 \text{ J} \]

\[ \text{Chemical energy} = \text{Work/eff} = \frac{1962 \text{ J}}{0.1} = 19620 \text{ J} \]

\[ \#\text{Calories} = \frac{19620 \text{ J}}{4184 \text{ J/Cal}} \approx 4.69 \text{ Cal} \]
Which of the following is correct concerning temperature?

A. The average kinetic energy of molecules in a gas increases at the temperature is increased.
B. Thermal motion is highly organized
C. As a gas is cooled, the molecules move more rapidly.
D. Temperature is a measure of the average potential energy of atoms.
E. Temperature is not related to energy.
Entropy

Entropy is a measure of the number of possible ways to arrange a system. Which is correct?

A. Molecules in a gas usually are moving together in the same direction.

B. The entropy of 10 heads is higher than the entropy of 5 heads and 5 tails.

C. In all closed systems the entropy never decreases in any process.

D. We can reduce entropy by adding heat.

E. We can reduce entropy by adding more coins to a pile.
Energy and Entropy - Pendulum Example

The thermal energy (heat) is "lost"
The Second Law of Thermodynamics

Which of the following are a statement of the second law of thermodynamics?

• Energy is conserved in a closed system
• The entropy of a system could decrease by external influences
• With no external influence, entropy is conserved
• **With no external influence, entropy always increases**
• With no external influence, entropy always decreases
Quantum Mechanics Review

• Light can be described as an electromagnetic wave or a little bundle of energy (a photon). Light has particle and wave character.

• Waves can overlap – this is called interference

• Particles, for example electrons, have wave and particle properties.

• The thing that is waving in the case of a particle is probability. The square of the height of the wave (wave function) is a measure of the probability density.

• All objects (atoms, molecules, etc.) exist in defined states of energy. The energy is quantized (quantum mechanics)
The Uncertainty Principle

What is the meaning of the Uncertainty Principle?

\[ \Delta x \Delta p \geq \frac{\hbar}{4\pi} \]

A. The entropy of a closed system always increases.
B. It is not possible to know the exact position and momentum of a particle at the same time.
C. It is not possible to ever know the exact position of a particle.
D. Small objects have a wave function.
E. Energy is conserved in a closed system.
Antiparticles and Antimatter

- All particles have a corresponding anti-particle with opposite quantum numbers. We write the anti-particle with a bar over the top, e.g. proton – p, anti-proton – $\bar{p}$
- Antimatter (matter made of anti-particles) is very difficult to make. It can artificially be produced only at large particle accelerators (“atom smashers”).
- Matter and anti-matter are created naturally in pairs
- So far the total amount of antimatter ever produced by humankind is a few grams.
Neutrinos

• Neutrinos are subatomic particles that do not have charge. They only interact via the weak force.
• These are very unusual particles and we still don’t know much about their properties. They have a mass, but it is so small we have not been able to measure it.
• They account for about 2% of the universe but interact weakly. One light-year of lead would have only a 50% chance of stopping one.
Equations – sort of

Rules for Feynman Diagrams:

1). The number of leptons and baryons must be conserved.

2). Charge must be conserved.
Some examples

Is the following allowed? Production of a quark and anti-quark by a collision of an electron and an anti-electron.

<table>
<thead>
<tr>
<th>Name</th>
<th>Charge</th>
<th>Lepton</th>
<th>Baryon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up quark</td>
<td>-1/3</td>
<td>0</td>
<td>1/3</td>
</tr>
<tr>
<td>Down quark</td>
<td>2/3</td>
<td>0</td>
<td>1/3</td>
</tr>
<tr>
<td>electron</td>
<td>-1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>neutrino</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron + anti-electron</td>
<td>quark + anti-quark</td>
</tr>
</tbody>
</table>
Some examples

<table>
<thead>
<tr>
<th>Baryon</th>
<th>Lepton</th>
<th>Charge</th>
<th>Before</th>
<th>After</th>
<th>Name</th>
<th>Charge</th>
<th>Lepton</th>
<th>Baryon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron +</td>
<td>0 + 0</td>
<td>1/3 +</td>
<td>anti-electron</td>
<td>1/3 + (-1/3)</td>
<td>Up</td>
<td>-1/3</td>
<td>0</td>
<td>1/3</td>
</tr>
<tr>
<td>anti-electron</td>
<td>0 + 0</td>
<td>quark + anti quark</td>
<td></td>
<td></td>
<td>Down quark</td>
<td>2/3</td>
<td>0</td>
<td>1/3</td>
</tr>
<tr>
<td>1 + -1</td>
<td>0 + 0</td>
<td>electron</td>
<td></td>
<td></td>
<td>electron</td>
<td>-1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>-1 + 1</td>
<td>1/3 + (-1/3)</td>
<td>neutrino</td>
<td></td>
<td></td>
<td>neutrino</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

allowed
Is this possible?

Yes, it is two quarks interacting via the electromagnetic force. Up quarks have electric charge of $+2/3$. 
Force Carriers

- Strong – Gluons – $g$
- Weak – Intermediate vector bosons – $Z, W$
- Electromagnetic – photon - $\gamma$

Two quarks interacting via the strong force
Feynman Diagrams and rules

Charge, baryon number, and lepton number are conserved

Consider the decay of a $^+$pion into an antimuon by the Weak force. Which diagram describes this process?

$$\pi^+ \quad ud$$

$$\mu \bar{\nu} \quad \mu \bar{\nu} \quad \mu \bar{\nu} \quad \mu \bar{\nu}$$

$$\gamma \quad \gamma$$

Correct
Other Examples

- Decay of $\pi^+$
  - $\mu^+ \bar{\nu}$
  - Charge of $W$ is not correct

- Decay of pion

- Wrong because electric force does not act on neutrinos

- Baryon and lepton not conserved