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>Matter Particles</th>
<th>Gauge Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2/3</td>
<td>Quark</td>
<td>Strong Force</td>
</tr>
<tr>
<td>-1/3</td>
<td>Quark</td>
<td>Electromagnetic Force</td>
</tr>
<tr>
<td>0</td>
<td>Lepton</td>
<td>Weak Force</td>
</tr>
<tr>
<td>-1</td>
<td>Lepton</td>
<td></td>
</tr>
<tr>
<td>anti-particles have opposite charge</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 (udd)
Made of quarks: Size 10^-15 m
A neutron has ddu
Closer to what a proton really looks like

![Proton Diagram](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</td>
<td>quarks, electrons (leptons), neutrinos</td>
<td>$10^{-18}$ Only 0.001 width of proton</td>
</tr>
<tr>
<td>Gravity</td>
<td>$6 \times 10^{-39}$</td>
<td>Graviton (?)</td>
<td>anything with mass</td>
<td>infinite</td>
</tr>
</tbody>
</table>

Our Picture of Force

A charge creates a field…

Picture of the field

Feynman diagram

Virtual particles can exist for a short time.

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 $1.6 \times 10^{-19} \text{C}$.

- The force between two charges is:
  \[ F = \frac{k q_1 q_2}{r_{12}^2} \]
  where $k = 8.99 \times 10^9 \text{Nm}^2\text{C}^{-2}$.

- Example (inverse square law): 4 times the distance
  \[ F_{4d} = \frac{k q_1 q_2}{(4r_{12})^2} = \frac{1}{4^2} \frac{k q_1 q_2}{r_{12}^2} = \frac{1}{16} \frac{k q_1 q_2}{r_{12}^2} = \frac{1}{16} F_d \]

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

- 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)

Note: we could make similar maps for all the fields in nature (gravity, weak, EM, strong).
Sample Problem

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

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

Simple Problem

\[ \mathbf{F} = \mathbf{E} \cdot q \]

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:

\[ \mathbf{F} = 15.5 \text{ N/C} \times 1.5 \text{ C} = 23.3 \text{ N} \]

Flow of Charge - Current

- Batteries are like pumps that lift charge to a higher potential. The charge flows down the hill to the other side of the battery.

A battery is like a pump.

Moving Charge does work on the way down
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 1m? Assume people are 10% efficient in converting chemical energy to work.
  \[ \text{Work} = mgh = 200 \times 9.81 \times 1 = 1962 \text{ J} \]
  \[ \text{Chemical energy} = \frac{\text{Work}}{\text{eff}} = \frac{1962 \text{ J}}{0.1} = 19620 \text{ J} \]
  \[ \text{Calories} = \frac{19620 \text{ J}}{4184 \text{ J/Cal}} = 4.69 \text{ Cal} \]

Which of the following is correct concerning temperature?

A. The average kinetic energy of molecules in a gas increases as 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

Energy

Potential E (mgh)

Kinetinc E (1/2)mv^2

Potential

Kinetic

Potential

The thermal energy (heat) is “lost”

Diagram for a real pendulum

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?

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

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 – $\bar{p}$ 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>$-\frac{1}{3}$</td>
<td>0</td>
<td>$\frac{1}{3}$</td>
</tr>
<tr>
<td>Down quark</td>
<td>$\frac{2}{3}$</td>
<td>0</td>
<td>$\frac{1}{3}$</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>

Before | After
--- | ---
electron + anti-electron | quark + anti-quark
Some examples

<table>
<thead>
<tr>
<th>Baryon</th>
<th>Lepton</th>
<th>Charge</th>
<th>Name</th>
<th>Charge</th>
<th>Lepton</th>
<th>Baryon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron +</td>
<td>1/3 + (-1/3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>anti-electron</td>
<td></td>
<td></td>
<td>Quark + anti</td>
<td>-1/3</td>
<td>0</td>
<td>1/3</td>
</tr>
<tr>
<td>0 + 0</td>
<td></td>
<td></td>
<td>quark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 + -1</td>
<td>0 + 0</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></td>
<td></td>
<td></td>
<td></td>
<td></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 - γ

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?

Two quarks interacting via the strong force
Other Examples

\[ \pi^+ (u\bar{d}) \]

Decay of pion

Charge of W is not correct

Wrong because electric force does not act on neutrinos

\[ \mu^- \bar{\nu}_\mu, \mu^+ \bar{\nu}_\mu, \bar{\mu}^- \nu_\mu \]

Wrong because electric force does not act on neutrinos

\[ W^+ \rightarrow u \bar{d}, W^- \rightarrow d \bar{u}, \gamma \]

Baryon and lepton not conserved