Today – Exam#2 Review

- Exam #2 is Thursday March 15 in this room, BPS 1410
- Extra Credit Projects: Urban Legend and 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>guage particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2/3</td>
<td>Quark u</td>
<td>Strong Force</td>
</tr>
<tr>
<td>0</td>
<td>Lepton e</td>
<td>Electromagnetic Force</td>
</tr>
<tr>
<td>-1</td>
<td>neutrino e</td>
<td>Weak Force</td>
</tr>
<tr>
<td>-1</td>
<td>anti-neutrino e</td>
<td></td>
</tr>
</tbody>
</table>

anti-particles have opposite charge

scalar particle(s) H
T. Kondo

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
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.

Why is the sky blue?

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 1.6E-19C.
- How many electrons make up a charge of -2.0 C?
  \[
  \text{number} = \frac{\text{charge}}{\text{charge/electron}} = \frac{-2.0C}{-1.6 \times 10^{-19}} = 1.25 \times 10^{19}
  \]
- The force between two charges is:
  \[
  F = \frac{kq_1q_2}{r_{12}^2}; \quad k = 8.99 \times 10^9 \text{Nm}^2\text{C}^{-2}
  \]
- Example (inverse square law): 4 times the distance
  \[
  F_{4d} = \frac{kq_1q_2}{(4r_{12})^2} = \frac{1}{16} \frac{kq_1q_2}{r_{12}^2} = \frac{1}{16} \frac{kq_1q_2}{r_{12}^2} = \frac{1}{16} F_d
  \]
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
• North pole of a compass points north in northern hemisphere
• North pole of a compass points south in southern hemisphere
• North pole of a compass points towards the north in the southern hemisphere

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?

\[ E = -\frac{\Delta V}{\Delta x} = \frac{(0V - 80V)}{(4m - 0m)} = 20.0 \frac{V}{m} = 20.0 \frac{N}{C} \]
**Electric field** is the rate of change of potential with position.

**Sample Problem**

![Graph of Electric Potential vs Position](image)

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:**

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

**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.

![Diagram of Battery](image)

A battery is like a pump.

**Conductor**

Electrons hit bumps, but are free to roll. As they go over the bumps, they generate heat.

![Conduction Band Diagram](image)
Electrons are not free to roll.

No resistance to flow (also no use of energy)

The following is a picture of a reaction:

Start with some initial mass (kg) → Something happens → End up with some final mass (kg)

Some fraction, f, is converted to energy

f - see the table on the next page

The amount of energy is:

\[ E = m_{\text{converted}} c^2 \]

\[ m_{\text{converted}} = (\text{Mass to start}) \times \text{fraction} \]
**Fraction of Energy Converted**

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Fraction</th>
<th>Example</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matter-Antimatter Annihilation</td>
<td>1</td>
<td>No common example</td>
<td>1</td>
</tr>
<tr>
<td>Fusion</td>
<td>0.007</td>
<td>Power source of the Sun</td>
<td>143</td>
</tr>
<tr>
<td>Fission</td>
<td>0.001</td>
<td>Nuclear power plant</td>
<td>1000</td>
</tr>
<tr>
<td>Chemical</td>
<td>1x10^-10</td>
<td>Burning coal</td>
<td>10^10</td>
</tr>
<tr>
<td>Mechanical</td>
<td>1x10^-15</td>
<td>Compressing a spring</td>
<td>10^{15}</td>
</tr>
</tbody>
</table>

Know the relative masses required to generate the same amount of energy.

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**Einstein’s Theory of General Relativity**

- Says that space and time are connected into a 4D space-time. Clocks run slow near mass.
- Mass curves space. This is the explanation of gravity and why gravitational mass is the same as the mass in \( F = ma \).
- Acceleration and gravity are related!
- Acceleration in one direction feels like gravity in the other.

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**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.

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**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.
\[
\text{Work} = mgh = 200 \times 9.81 \times 1 = 1962 \text{ J}
\]
\[
\text{Chemical energy} = \text{Work/eff} = 1962 \text{ J} / 0.1 = 19620 \text{ J}
\]
\[
\# \text{Calories} = \frac{19620 \text{ J}}{4184 \text{ J/Cal}} = 4.69 \text{ Cal}
\]
Which of the following is correct concerning temperature?

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

The Electromagnetic Spectrum

Speed = \lambda \cdot f
\lambda – wavelength
f – Frequency, Hz
(1/period)(1/s)

Energy = h \cdot f
h = 6.625 \times 10^{-34} \text{ Js}
= 4.136 \times 10^{-15} \text{ eVs}

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).
An example

One version of the uncertainty principle says that for a short period of time, particles can be created out of nothing. They can pop in and out of existence. For a time of 1.2E-15 s, what is the maximum energy photon than can exist?

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

\[ \Delta E = \frac{h}{4 \pi \Delta t} = 4.136 \times 10^{-15} \text{ eVs} \]

\[ 4 \cdot 3.1415 \cdot 1.2 \times 10^{-15} \text{ s} \]

\[ \Delta E = 0.274 \text{ eV} \]

Antiparticles and Antimatter

- All particles have a corresponding anti-particle with opposite quantum numbers
- 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.
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?

\[
\begin{array}{c}
\pi^+ \rightarrow u\bar{d} \\
\mu^+ \rightarrow \mu^- + \gamma
\end{array}
\]

Other Examples

Wrong because electric force does not act on neutrinos

Baryon and lepton not conserved

Decay of pion

Charge of W is not correct

Wrong because electric force does not act on neutrinos