Announcements…

- **Homework 2** - due on Thursday. Please turn in a hard copy in class (i.e. not via SPARK)

- **TA Don Blair**, office hours - Tuesdays 2-4PM in Hasbrouck 414 (or by appointment dwblair@physics.umass.edu)

- **Honors section** - first meeting is on Thursday @ 4PM in the Blue Wall. (I’ll get there a few minutes early and find a big table)
Energy news items for 9/18/07....

New York Subpoenas 5 Energy Companies
By FELICITY BARRINGER and DANNY HAKIM

Attorney General Andrew M. Cuomo of New York has opened an investigation of five large energy companies, questioning whether their plans to build coal-fired power plants pose undisclosed financial risks that their investors should know about.

Arctic Ice Melt Opens Northwest Passage
By JAMEY KEATEN – 1 day ago

PARIS (AP) — Arctic ice has shrunk to the lowest level on record, new satellite images show, raising the possibility that the Northwest Passage that eluded famous explorers will become an open shipping lane.

The European Space Agency said nearly 200 satellite photos this month taken together showed an ice-free passage along northern Canada, Alaska and Greenland, and ice retreating to its lowest level since such images were first taken in 1978.

The waters are exposing unexplored resources, and vessels could trim thousands of miles from Europe to Asia by bypassing the Panama Canal. The seasonal ebb and flow of ice levels has already opened up a slim summer window for ships.
Discussion questions on Cuomo & Coal article

Why are so many new coal power plants being proposed nationwide?

Why are environmental groups and some State’s opposing new coal power plants?

Should this sort of environmental policy be determined at the State or Federal (or global) level?

What are the risks to investors in new coal power plants that might not be adequately disclosed?

Discussion questions on Artic Ice article

Is it a great thing, or is it ironic, that thawing of the artic ice will make huge fossil fuel deposits in the region much more accessible?

How will/should nations handle the question of who gets to exploit these resources? Does this seem more likely to lead to increased international cooperation, or to increased conflict?
The stability of the atom was a great puzzle for physicists early on in the 20th century…

The solution lies in what physicists call **quantum mechanics**.

According to quantum mechanics, the electrons can only occupy orbits having certain “quantized” energies.

Electrons can transition between these distinct energy levels by emitting or absorbing photons of the correct energies. The lowest energy level, known as the ground state, is stable.
The atoms of interest to us will be mostly, in addition to hydrogen, carbon and oxygen, which occupy the 6th and 8th spots on the periodic table.

The energy levels of these atoms (except for hydrogen) cannot be calculated exactly because of the interactions between the multiple electrons, but the basic physical picture is clear. Electrons can occupy orbitals much like those of the hydrogen atom.

However, they cannot all sit in the lowest energy level, closest to the nucleus!

This is a consequence of the Pauli exclusion principle - no two electrons can occupy the same energy level.

Moving up the periodic table from hydrogen, as electrons are added they must occupy higher and higher energy levels.

Wolfgang Pauli - one of the founders of quantum mechanics
Another aside….

The Pauli exclusion principle turns out to be another very deep fact of physics.

All fundamental particles in nature can be put into two categories - Fermions & Bosons.

Matter particles like protons, neutrons & electrons are all fermions, while force carriers like photons, gluons and gravitons are all bosons.

Identical fermions are forbidden from occupying the same energy level, while bosons are not…
Back to atoms & some basic chemistry

The higher energy levels are further away from the nucleus. It is these outermost electrons that determine how chemically reactive an element is.

Roughly speaking, the most stable elements are those which have 8 electrons filling their outermost “shell”. These are the inert gases that occupy column 8 of the periodic table.

Elements in columns 1 through 7 will tend to lose or gain electrons in order to achieve a filled outer shell. This leaves them having a net positive or negative charge (which is known as ionization). Positively and negatively charged ions can join together to form molecules. This is called ionic bonding.

We’ve now entered the realm of chemistry
Some of the most familiar molecules can be understood in terms of ionic bonding.

Elements in column 1, such as hydrogen, need to lose an electron to complete a shell.

Elements in column 6, such as oxygen, need to acquire 2 electrons to complete a shell.

The water molecule $\text{H}_2\text{O}$ satisfies both these needs…

Elements in column 4 have many options for bonding. They can attain a complete shell either by losing or gaining 4 electrons.

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Carbon dioxide - $\text{CO}_2$

Methane - $\text{CH}_4$

The simplest hydrocarbon & main component of natural gas.

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Physics 190E: Energy & Society
Fall 2007
The chemistry of carbon is so rich and important for life that it forms its own special name - **organic chemistry**. We will be particularly interested in certain organic molecules - hydrocarbons, chains of carbon and hydrogen atoms, possibly with other additions - that are the components of fossil fuels. We’ll return to this in more detail later on.

Back to energy….

The chemical energy of a molecule is the sum of the energies of all its electrons.

This is quite a difficult thing to calculate. Fortunately, we are most interested in how these energies change in chemical reactions. These **changes in energy** are things that can be measured.
Chemical reactions are classified as being either **exothermic** or **endothermic**.

In a chemical reaction there are input molecules and output molecules.

**In an exothermic reaction**, the chemical energy of the input molecules is greater than that of the output molecules. The excess energy is released as heat and/or light.

\[
\text{input molecules} \rightarrow \text{output molecules} + \text{energy}
\]

**In an endothermic reaction**, the chemical energy of the input molecules is less than that of the output molecules. Energy in the form of heat and/or light must be added in order for the reaction to proceed.

\[
\text{input molecules} + \text{energy} \rightarrow \text{output molecules}
\]
Burning or combustion is an exothermic reaction

Let’s look at an example…

Methane - CH₄ - is the principle component of natural gas. Methane burns by combining with oxygen via the reaction.

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]

4 oxygen atoms combine with one methane molecule to yield one molecule of carbon dioxide and two water molecules.

People say that natural gas burns “cleanly”, because there is nothing nasty like sulfur among the combustion products…

How much heat is released in this reaction?
The sum of the electron energies on the left turns out to be more than the sum of those on the right. The excess energy comes away as heat (kinetic energy of atoms). The amount of resulting thermal energy is known as the heat of combustion for the reaction.

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
\]

The heat of combustion for a single methane molecule is \(1.3 \times 10^{-18}\) J.

Often the heat of combustion is quoted per kilogram of the material being burned. For methane, this works out to be \(55 \times 10^6\) J/kg = 55 MJ/kg.

Another way to quote the heat of combustion is in terms of an energy per mole of the burning material.

Having a mole of some kind of object means having a particular very large number of them. This number \(N_A\) is known as Avogadro’s number and is given approximately by \(N_A = 6.02 \times 10^{23}\).
The mole is a measure frequently used in chemistry…

In addition to its atomic number, an atom has an atomic mass number. The atomic mass number counts the number of protons plus the number of neutrons in the atomic nucleus.

For example, the atomic mass number of (the most common isotope of) carbon is 12, because a carbon nucleus has 6 protons and 6 neutrons.

The modern (SI) definition of the mole is the number of carbon-12 atoms in 12 grams = .012 kg of carbon-12.

Moles are useful because chemical reactions deal with numbers of atoms, and a mole of some atomic element or molecule is a reasonable macroscopic amount.

Finally, the heat of combustion of methane is 802 kiloJ/mole
According to Wikipedia

http://en.wikipedia.org/wiki/Mole_(unit)#Moles_of_everyday_entities

**Moles of everyday entities**

- Given that the volume of a grain of sand is approximately $10^{-12}$ m$^3$, and given that the area of the United States is about $10^{13}$ m$^2$, it therefore follows that a mole of sand grains would cover the United States in approximately one centimeter of sand.

- A human body contains very roughly one hundred trillion cells; there are roughly six billion people on Earth; so the total number of human cells on the planet is approximately $(100 \times 10^{12}) \times (6 \times 10^9) = 6 \times 10^{23}$, which is very close to one mole.

- Since the Earth has a radius of about 6400 km, its volume is approximately $10^{21}$ m$^3$. Since about 500 large grapefruit will fit in one cubic meter, it therefore follows that a mole of grapefruit would have approximately the same volume as the Earth.
Back to burning….why do we need matches?

Fires need to be lit, but then once lit, they keep going. Why is this? This phenomenon has its origin at the molecular level.

The input molecules need to **collide with a certain minimum kinetic energy** in order overcome an energetic barrier.

The barrier is there because, as the input molecules approach one another, their outer electrons will repel each other.

The height of this barrier is known as the **activation energy** for the reaction.

http://en.wikipedia.org/wiki/Reaction_coordinate
The activation energy is generally supplied by heating up the chemical inputs.

Even at low temperatures a reaction with an activation energy will happen at some slow rate, because the distribution of energies amongst molecules at a given temperature always includes some with high enough energies.

Adding heat raises the fraction of molecules with sufficient energies to overcome the barrier and the reaction proceeds faster.

Lighting a fire with a match supplies the activation energy for the first reactions to happen. The energy released by these first reactions then contributes to the activation energy for subsequent reactions and the fire sustains itself.
Enzymes (or more generally catalysts) provide alternative pathways for a reaction to proceed with lower activation energies, thereby increasing reaction rates.
More combustion …..

Hydrogen burns via the simple reaction

\[ 2 \ H_2 + O_2 = 2 \ H_2O + 572 \ \text{kJ/mol} \]

This reaction will be important when we talk about the “hydrogen economy”.

Because the only combustion product is water, hydrogen combustion is invisible. In this picture you see the skin of the zeppelin burning….
**Photosynthesis**….burning in reverse….an endothermic reaction

\[ 6 \text{ CO}_2 + 6 \text{ H}_2\text{O} + \text{photons} = \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2 \]

Energy input in the form of light

Glucose - a simple sugar that cells use as a source of energy

This formula summarizes the result of an extremely complex series of biochemical steps that begins (in plants) with the absorption of a photon by a molecule of chlorophyll….

Photosynthesis is essentially a way for organisms to convert energy in the form of light into chemical energy.
How is photosynthesis important for our purposes in this course?….many reasons

- The oxygen in our atmosphere comes from photosynthesis. We’re concerned about the state of our atmosphere - global warming & climate change. Therefore, we need some understanding of why our atmosphere is the way it is today?

- Fossil fuels originated from the compression and heating of ancient organic materials over geological time scales. Much of the chemical energy we make use of today was built up by photosynthetic processes long ago.

- Biofuels, which use the sun’s energy to generate chemical energy via photosynthesis today, are an important possible substitute for fossil fuels in our society’s energy diet. (Of course this raises many other issues….)

We’ll talk about the first one of these now and leave the third others for later…
Photosynthesis and the “Oxygen Catastrophe”

\[6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{photons} = \text{C}_6\text{H}_12\text{O}_6 + 6 \text{O}_2\]

Photosynthesis takes in carbon dioxide and gives off oxygen. It turns out that the oxygen in Earth’s atmosphere, which is responsible for life as we know it, was generated over hundreds of millions of years by primitive organisms via photosynthesis.

Dry air today is composed roughly of nitrogen 78%, oxygen 21%, argon 1% together with small amounts of other atoms & molecules such as \text{CO}_2.

\text{CO}_2 presently has a concentration of about 0.04% in the atmosphere.

The atmosphere also contains a variable amount of water vapor (approximately 1%).

In addition to providing the air we breath, it shields the Earth’s surface from UV radiation from the sun which is harmful to life.
But, the composition of the atmosphere was not always like this ….. Geologists say that Earth has had 3 atmospheres over time - the present composition being the 3rd.

The Earth formed approximately 5 Billion years ago and was extremely hot. Earth’s **first atmosphere** is believed to have been mainly composed of the light gasses hydrogen and helium.

This first atmosphere was most likely dispersed into space by the solar wind - the stream of high energy charged particles that are ejected from the outer layers of the sun.

In later epochs, the atmosphere is largely protected from the solar wind by Earth’s magnetic field, which is generated within Earth’s iron core. In these early molten days, the core had not yet formed.

Today, we see the solar wind’s interactions with Earth’s magnetosphere in the auraora borealis and geomagnetic storms that interfere with power grids.