Announcements for Thursday - September 20th

• Homework 2 due today

• Honors section has first meeting today @ 4PM in Blue Wall

• Homework 3 due next Thursday - focuses on thermal energy & chemical energy, with a bit more mechanical energy as well…

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Homework #3
Physics 190E - Energy and Society
Due Thursday, September 27th

1. Average human body temperature is 98.6°F.
   a) What is this temperature in Celsius?
   b) What is it in Kelvin?

2. A container holds two moles of a simple atomic gas at temperature 98.6°F.
   a) What is the total thermal energy of the gas?
   b) What is the average kinetic energy of a single atom in the gas?
   c) If the total mass of the gas is 0.002kg, what is the mass of a single atom?
   d) What is the velocity of an atom that has the average kinetic energy?

3. An electric fan runs inside the container of gas from problem 2. The fan draws 10W of electric power. Assume that all the electric energy drawn by the fan is converted to mechanical energy and that all this mechanical energy goes into heating up the gas. How much will the gas heat up in the course of an hour? Express your answer in degrees Kelvin.

4. How much heat is released by burning 5 moles of methane?

5. Pure carbon has a heat of combustion of 33MJ/kg. How much energy would be released by burning 15 tons of coal, assuming it to be pure carbon?

6. You want to throw a stone up to a height of at least 25m.
   a) If you throw it straight up in the air, what is the minimum velocity must you give it?
   b) What velocity will it have when it returns to the ground (just before it hits)?

7. A heat engine operates between two temperatures such that its maximum possible efficiency is 80%.
   a) If the upper temperature is 80°C, what is the lower temperature? Express your answer in degrees Celsius.
   The heat engine takes in 2500J of energy at the upper temperature.
   b) How much work does it do?
   c) How much waste heat is ejected at the lower temperature?

8. (short answer) What happens at absolute zero temperature?
We finished up last time by talking about photosynthesis. We were starting into a discussion about how ancient photosynthetic organisms created Earth’s present oxygenated atmosphere and made life as we know it possible.

Most of us are familiar with the notion that the vast Amazon rainforests are important for maintaining our atmosphere in good condition.

It’s fascinating to learn that since very early times the biosphere and the atmosphere have formed a deeply interactive system - each influencing the development of the other…
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 CO\(_2\).

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.
Earth’s **second atmosphere** formed from volcanic outgassing, which brought out carbon dioxide, water and nitrogen from the Earth’s interior.

As the Earth cooled, water precipitated out of the atmosphere to form oceans. A great deal of CO$_2$ was dissolved into the oceans (as it is today).

There was very little O$_2$ in the atmosphere at this point and the earliest life forms did not need oxygen. As life evolved on Earth’s surface, most of the remaining CO$_2$ was converted into molecular oxygen through photosynthesis.

Prominent in this process were cyanobacteria (aka blue-green algae) which formed large mats in shallow waters.
Nitrogen and oxygen were left as the primary components of Earth’s **third atmosphere**.

Ironically, the high level of oxygen accumulating is the atmosphere proved toxic to the anearobic organisms partly responsible for creating it - hence the name **oxygen catastrophe**.

As we move into an era in which the impact of human civilization on the atmosphere & climate is becoming important, it’s fascinating to learn that the atmosphere, as we know it, owes its existence to life forms.
Let’s do a recap of where we are in working through the basic physics of energy in its various forms…

1. Kinetic energy
2. Gravitational potential energy
3. Thermal energy
4. Chemical energy
5. Electrical energy
6. Solar energy
7. Nuclear energy

Before we work on items 5, 6 & 7, we’ll spend some time talking about just how much energy we use in our society.

We’ll then move on to focus on various aspects of fossil fuels - oil, natural gas & coal
Start by getting some perspective…..

<table>
<thead>
<tr>
<th>Total world energy consumption in 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_{2004} = 447 \text{ Quads} )</td>
</tr>
<tr>
<td>( = 447 \times 10^{15} \text{ BTU} )</td>
</tr>
<tr>
<td>( = 0.471 \times 10^{21} \text{ J} )</td>
</tr>
<tr>
<td>( = 0.471 \text{ ZJ} )</td>
</tr>
</tbody>
</table>

1 zettaJoule = \( 10^{21} \) Joule

Let’s think very simply about what we have to work with to achieve a sustainable energy solution for society. If we want to do without the forms of stored energy here on earth - e.g. fossil fuels and nuclear fuels - then (for the most part) we have to make do with Earth’s daily income of energy from the sun.

How much is this?
But first…

Can you think of any forms of energy we might use that don’t fall in these categories (i.e. not fossil, nuclear or solar related)?
How about….

**Geothermal energy** - draws from the thermal energy stored in our planet since its earliest days….  

Iceland’s high concentration of volcanoes allows it to get about 17.2% of its electricity from geothermal power plants & 87% of its residential heat and hot water needs.

In addition, hydropower provides almost all the rest of Iceland’s electricity, with fossil fuels accounting for less than 1%.

Swimmers in hot springs with geothermal power plant in background, near Reykjaniesbaer, southwestern Iceland.

Data from *Energy Statistics in Iceland, 2005*
And also….

**Tidal energy** - relies on the Moon’s gravitational pull on Earth’s oceans

Tidal power schemes come in two types, making use of the tide’s kinetic energy (i.e. moving water) and potential energy (i.e. height difference between high and low tides) respectively.

A few tidal power plants have been built. Many more are being planned or considered. There are many environmental concerns regarding marine life.

More good paper topics
The only tidal power station in North America is located on an inlet of the Bay of Fundy, known for having the world’s highest tides.

The Annapolis Royal Generating Station opened in 1984 and has an 18 MegaWatt generating capacity. The sluiceways of a dam across the Annapolis river are open as the tide comes in. At hide tide, the gates are closed. At low tide the water, the water behind the dam (stored at the high tide level) flows downhill through electric turbine generators. The station produces enough power for about 4500 households.

In 2004 a humpback whale followed fish through the open sluiceway and was trapped in the upper river for several days.

Back to how much solar energy is available to us on Earth? This turns out to be a complicated question…. As we’ll discuss later on.

A rough estimate of the average solar power striking the Earth’s surface is…

164 Watts/m$^2$

This is averaged over all of Earth’s surface, over day and night and over weather conditions.

How much does this add up to for the whole Earth in a year?

Earth’s surface area

Note: this total ignores wind energy which comes largely from solar energy absorbed by the atmosphere.

E$_{\text{solar}}$ = (5.10 x 10$^{14}$ m$^2$) (365 days/year) (24 hours/day) (3600 seconds/hour) (164 W/m$^2$)

= 2.63 x 10$^{24}$ J/year = 2630 ZJ
Let’s compare numbers…..

\[ E_{2004} = 0.471 \text{ ZJ} \quad E_{\text{solar}} = 2630 \text{ ZJ} \]

This gives an encouraging ratio \[ \frac{E_{\text{solar}}}{E_{2004}} = 5600 \]

The amount of solar energy reaching Earth’s surface is 5600 times more than we use, but can we make use of enough of it? That is the big question that needs to be answered.
Before we work on our energy future, we’re going to look in more detail at where we’re at today …..

Let’s focus on energy consumption and sources in the U.S. market.


Comparing to the 2004 figure of 447 Quads for total world consumption, we see that the U.S. is accounting for somewhere in the range 20%-25% of the total.
The EIA keeps very precise track of the sources of energy consumed in the U.S. and also what it is used for.

Source: EIA - 2006 Annual Energy Review
http://www.eia.doe.gov/emeu/aer/contents.html
On the supply side, the numbers for 2006 are…

<table>
<thead>
<tr>
<th>Source</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Fuels</td>
<td>84.76 Quads</td>
</tr>
<tr>
<td>Nuclear Energy</td>
<td>8.21 Quads</td>
</tr>
<tr>
<td>Renewables</td>
<td>6.84 Quads</td>
</tr>
</tbody>
</table>

We see that fossil fuels currently provide 85% of the energy consumed in the U.S. This is further broken down into types of fossil fuels…

<table>
<thead>
<tr>
<th>Source</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum</td>
<td>39.76 Quads</td>
</tr>
<tr>
<td>Coal</td>
<td>22.51 Quads</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>22.43 Quads</td>
</tr>
</tbody>
</table>

Petroleum accounts for 47% of total fossil fuel consumption in the U.S.
Before moving on, let’s look at how the EIA breaks down energy consumption.

And then even further within a given sector

Later, when we talk about energy conservation and efficiency in our society, we’ll want to come back to such graphs to understand where progress needs to be made …
For example, we see that almost half of residential energy use is for heating. So, improving house insulation can yield major energy savings….

Let’s now focus on fossil fuels which currently supply 85% of our energy needs in the U.S. (The worldwide figure is quite similar)

Fossil fuels are hydrocarbons found within the top layer of the Earth’s crust.

The familiar fossil fuels are oil, coal and natural gas. Tar sands and oil shale are less familiar but may become more economically important
What are hydrocarbons?

**Pure hydrocarbons** are chains of carbon and hydrogen atoms, such as …

**Impure hydrocarbons** also include e.g. sulphur and nitrogen impurities in the chain.

There are many different hydrocarbon molecules occurring in fossil fuels. Some of the more familiar ones are…..

**Alkanes** (also known as paraffins) have the general chemical formula $C_nH_{2n+2}$ with $n=1,2,3,\ldots$ For a given value of $n$, there may also be more than one possible configuration of atoms.

The simplest alkanes are…

<table>
<thead>
<tr>
<th>$n$</th>
<th>$C_nH_{2n+2}$</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$CH_4$</td>
<td>methane</td>
</tr>
<tr>
<td>2</td>
<td>$C_2H_6$</td>
<td>ethane</td>
</tr>
<tr>
<td>3</td>
<td>$C_3H_8$</td>
<td>propane</td>
</tr>
<tr>
<td>4</td>
<td>$C_4H_{10}$</td>
<td>butane</td>
</tr>
</tbody>
</table>

and so on through pentane, hexane, heptane, octane,… with increasing number of carbon atoms.
The chemical bonds in alkanes are all single bonds, involving only single pairs of shared electrons.

Isobutane is an example of a branched alkane

A more detailed illustration of the sharing of electrons in methane.

Simple chain alkanes
Alkenes are chains of carbon and hydrogen atoms including at least one double bond between carbon atoms in which two pairs of electrons are shared…. Here again we find familiar names.

The simplest alkenes, those with only one double bond, have the formula $C_nH_{2n}$ with $n = 2, 3, 4, \ldots$

Ethylene $C_2H_4$ is the simplest alkene

Propylene $C_3H_6$
Butylene $C_4H_8$

Alkenes are heavily used in the petrochemical industry. For example the long chain polymers, polyethylene and polypropylene are built by stringing together ethylene or propylene molecules. They are used to make plastics.
The process of stringing together a great number of basic units - **monomers** - to make a long, repeating chain molecule - a **polymer** - is known as **polymerization**.

In the polymerization of ethylene, the double bonds are undone in order to bond the neighboring monomers into a polyethylene chain.
Fossil fuels are the main source of hydrocarbons of all sorts. The petrochemical industry - and our supply of plastic and many other goods - relies on cheap and plentiful oil supplies…. This represents another competing need (along with energy) for fossil fuel supplies.
How did fossil fuels form?

The **biogenic** theory of fossil fuel formation represents the predominant view of geologists. In this view all fossil fuels formed from the remains of ancient plant and (microscopic) animal life through heat and compression over geologic time scales.

Many details of these processes remain unclear, but some basic principles are well established and serve as successful guides for finding fossil fuel deposits.

**Petroleum** (crude oil) formed under ancient seabeds from accumulations of plankton within sedimentary rock formations. Petroleum can move through porous rocks and accumulates in pools under certain types of rock formations called traps that can block its passage.

**Oil fields** are not vast pools of oil, but rather porous rock formations permeated with oil.
Coal formed over continental land masses from the compression and heating of the remains of ancient vegetation in conditions of low oxygen (like a peat bog).

There are three basic forms of coal - lignite (brown coal), bituminous (soft) coal and anthracite (hard) coal - that are associated with different degrees and time spans of pressure and heating. Graphite results from still further heating and compression, but is difficult to ignite.

These different types of coal can be distinguished by (among other things) their hardness, density, levels of impurities, carbon and water content and heats of combustion.
Natural gas can form in association with either oil or coal and is often found in conjunction with oil and coal deposits. Natural gas is extremely mobile in porous rocks. It can migrate large distances and hence is sometimes found independent of coal or oil.

Natural gas poses a hazard in coal mines. It can be explosive at concentrations of 5% to 15%. Although it is non-toxic, it can also cause asphyxiation by displacing air.

A methane explosion at the Sago coal mine in West Virginia (January 2nd, 2006) led to the deaths of 12 miners who were trapped following the explosion. One trapped miner survived.
A good deal of the natural gas found in oil wells is either flared or vented to the atmosphere. This is a relatively small, but still significant source of greenhouse gas emissions. These practices take place because many oil wells lack the infrastructure for capturing natural gas and transporting for use to population centers.

Russia, with many oil fields in remote locations, followed by Nigeria are the world leaders in gas flaring.
Although on September 19th, it was reported that…

Russia will stop flaring associate gas - Ivanov

KHANTY-MANSIISK. Sept 19 (Interfax) - Russia will stop flaring associate gas during oil production, Acting First Deputy Prime Minister Sergei Ivanov said.

"We will not allow anyone to flare associate gas, at least in Russia. The decision has already been made," Ivanov said at a military industrial commission meeting on Wednesday that discussed the Russian fuel and energy complex.

Ivanov said flaring associate gas was "wasteful vandalism."

"We aren't rich enough yet to allow ourselves such a luxury, not to mention the environment," Ivanov said.

The Khanty-Mansiisk Autonomous District alone flares approximately 7.3-7.3 billion cubic meters of associate gas a year, regional Governor Alexander Filippenko said at the meeting.

He said that this was comparable to destroying 6.5 million tonnes of oil.
Heats of combustion…

<table>
<thead>
<tr>
<th>Coal Type</th>
<th>Heat Content (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>10-20</td>
</tr>
<tr>
<td>Bituminous</td>
<td>24-35</td>
</tr>
<tr>
<td>Anthracite</td>
<td>26-33</td>
</tr>
</tbody>
</table>