New feature on the course website

The goal of this is not to try to provide a comprehensive energy news service - you can find these online. I’ll try to post a new article on some interesting topic the day (or possibly night) before each lecture. We can start class with a couple of minutes of discussion.

I’m happy to get suggestions for articles as well…
Utility Will Use Batteries to Store Wind Power

By MATTHEW L. WALD

WASHINGTON, Sept. 10 — American Electric Power, a coal-burning utility company that is looking for ways to connect more wind power to its grid, plans to announce on Tuesday that it will install huge banks of high-technology batteries.

The batteries are costly and their use at such a big scale has not been demonstrated, but they may be an essential complement to renewable power, experts say.

“We’re looking at what we believe the grid of the future is going to be,” said Carl L. English, president of A.E.P. “We’re going to need a significant amount of storage if for no other reason than to take greatest advantage of alternative energy sources like wind power.”

The investment would position the company well if any of the 11 states in its service territory establish a minimum quota for renewable energy, or if Congress sets a national standard, company executives said; it would also help if carbon controls were instituted and wind power were to gain a financial advantage over coal.

An expert not involved in the program, Edgar DeMeo of Renewable Energy Consulting Services, said, “They must think there’s enough potential there so they want get a better handle on how it works.” But Mr. DeMeo and others said that wind energy had substantial room to grow before storage became necessary.

American Electric Power’s batteries will be used to smooth the power delivery from wind turbines. They can charge at night, when the wind is strong but prices are low, and give the electricity back the next afternoon, when there is hardly any wind but power prices are many times higher, company officials said. That strategy would reduce the amount of power generated from inefficient peak-demand units.

The batteries can also insert energy into the grid during brief voltage drops, reducing the chance of a blackout and stabilizing the grid for all users. They may also delay or eliminate the need for transmission upgrades in some areas, the company said.

Also some interesting comments on plug-in hybrid cars near the end of the article…

I also posted the AEP press release.
We’re considering a gas that’s made up of single atoms in a container. The atoms travel around in straight lines colliding occasionally with each other and with the walls of the container.

The number of atoms in a gas is immense (approximately $3 \times 10^{22}$ in a liter container at room temperature and pressure).

The pressure of a gas comes from collisions of the atoms with the walls of the container. The faster the atoms in the gas are moving, the higher the pressure.

The speed of the atoms is in turn related to temperature.
The average kinetic energy of gas atoms is …

\[
\frac{1}{2} m v^2 = \frac{3}{2} k_B T
\]

where \( k_B \) is known as Boltzmann’s constant and is given by

\[
k_B = 1.4 \times 10^{-23} \text{ J/K}
\]

and temperature is measured using degrees Kelvin.
(This is the K in the units of Boltzmann’s constant)

The total energy of the gas is just the sum for all the gas atoms.

\[
E_{gas} = \frac{3}{2} N k_B T
\]

\( N \) = number of gas atoms
Temperature scales

We are familiar with Fahrenheit temperatures and maybe also Celsius (centigrade) temperatures, but the SI units for temperature are degrees Kelvin, which scientists prefer for a number of reasons.

The Celsius temperature scale was established in 1742 by taking $T=0 \degree C$ to be the freezing point of water, $T=100 \degree C$ to be the boiling point of water, which seems very orderly.

The logic behind the Fahrenheit scale (1724) is somewhat murky. Fahrenheit has the advantage that outside temperatures range mostly between 0 and 100 degrees Fahrenheit.

Converting Celsius to Fahrenheit

$$\degree F = 32 + (1.8 \times \degree C)$$
Kelvin is an **absolute** temperature scale - in the sense that the zero of the Kelvin scale is the coldest possible temperature - what physicists call absolute zero.

At absolute zero temperature, all motion ceases …. We can see this from our formula for the kinetic energy of a gas.

\[
E_{\text{gas}} = \frac{3}{2} N k_B T
\]

The energy vanishes at zero temperature.

The basic idea is that one cools a system by extracting energy from it. Once everything stops moving, no more energy can be extracted, and the temperature can get no lower….
What is absolute zero on the Celsius scale? This is another question for the experimenters.

Already in the 18th century, it was noticed that as the temperature of a gas was lowered, its pressure went down as well. By extrapolation, it looked like the pressure would go to zero at an extremely low temperature.

The French physicist Guillaume Amontons in 1702 estimated this absolute zero temperature to be -240°C. This is reasonably close to the modern figure of T=-273.15°C for absolute zero.

Conversion between Celsius and Kelvin is simple because the degrees have the same size, only the zeroes of the two scales differ.

\[ ^\circ K = ^\circ C + 273.15 \]
How cold can things get?…. Is absolute zero temperature achievable?

Researchers routinely study the property of materials in the millikelvin range (10^{-3}K). Special materials can be made much colder. The record is 4.5 \times 10^{-10}K, a gas of sodium atoms at MIT in 2003.

The **3rd law of thermodynamics** implies that systems can get arbitrarily close to absolute zero, but it would take an infinite amount of time to cool something to T=0.
Back to thermal energy…

It’s easy to turn mechanical energy into thermal energy. Just rub your hands together. The friction of one hand moving against another generates heat.

Just as thermal energy is the kinetic energy of the atoms that make up a macroscopic system, friction comes from the forces between these atoms. We talk about macroscopic frictional forces, so that we don’t have to talk about all these separate microscopic forces.

Friction always wins out in the end in the real world. Eventually all motion ceases and all energy gets converted to heat. There are no perpetual motion machines….
What about going in the opposite direction, converting thermal energy into mechanical energy?

This is what we do all the time in car engines. We get heat from burning gasoline & the pistons convert it to mechanical energy.

In a car there is always some left over heat to be dissipated by the radiator & the exhaust. So, not all the heat energy is converted to mechanical energy.

The question becomes…How well can we do? Can thermal energy be transformed to mechanical energy with 100% efficiency, i.e. with no leftover thermal energy.
The answer is NO! There is a maximum possible efficiency for heat engines (as devices that convert thermal to mechanical energy are known).

An idealized heat engine has two reservoirs of thermal energy, one at a high temperature $T_H$ and one at a low temperature $T_C$.

In a car - $T_H$ is the temperature of combustion of the fuel/air mixture in the engine and $T_C$ is the temperature outside the exhaust pipe.

$\text{TE}_{in} =$ thermal energy entering heat engine

$\text{TE}_{out} =$ thermal energy exiting heat engine

$\text{ME}_{out} =$ mechanical work output

$\text{TE}_{in}$

$\text{ME}_{out} = \text{Work}$

$\text{TE}_{out}$
Conservation of energy implies that the total energy in equals the total energy out.

\[ TE_{in} = ME_{out} + TE_{out} \]

The efficiency of the heat engine determines what fraction of the thermal energy that enters comes out as mechanical work.

\[ \varepsilon = \frac{ME_{out}}{TE_{in}} \]

For any given values of \( T_C \) and \( T_H \), the maximum possible efficiency is another consequence of the second law of thermodynamics.

\[ \varepsilon_{max} = 1 - \frac{T_C}{T_H} \]

Perfect efficiency can happen only if \( T_C = 0 \) or if \( T_H = \infty \), neither of which is possible…

These temperatures are assumed to be measured in degrees Kelvin.
We see that basic physics sets limits on how efficiently heat engines can convert thermal energy into mechanical energy.

This is important, because nearly all the energy we utilize makes use of some sort of heat. We may think of steam power, e.g. steamships and steam locomotives, as something of the distant past. However, over 85% of the electricity we use in the U.S. is generated by steam driven turbines.

Whenever we burn something to generate mechanical or electrical energy we are using a heat engine. Nuclear power plants too….
Other lessons from heat engines…

\[ \varepsilon_{\text{max}} = 1 - \frac{T_C}{T_H} \]

There will always be waste heat from a heat engine… This is why power plants are often situated alongside rivers or other bodies of water. This can have serious environmental consequences. More on this later.

Another thing we learn is that whenever we can find a persistent temperature differential in nature, this presents an opportunity for generating mechanical (or electrical) power.

For example, ocean thermal energy conversion (OTEC) is a method for generating electricity which utilizes the temperature difference that exists between deep and shallow waters.
Unfortunately, this temperature difference is not too big and gives a relatively modest maximum efficiency.

Surface temperature - $T_H = 25^\circ C = 298K$
Temperature at 1km depth - $T_C = 10^\circ C = 283K$

Let’s calculate the maximum efficiency for an OTEC plant.

$$\varepsilon_{MAX} = 1 - \frac{T_C}{T_H} = 1 - \frac{283K}{298K} = .05$$

The maximum possible efficiency is around 5%, which sounds unpromising. However, the amount of thermal energy stored in seawater is immense. So, OTEC may still be worthwhile if (like many other alternative energy technologies) the price per kW-hr can be brought down….
We’ve now discussed energy in 3 different forms - kinetic energy, gravitational potential energy and thermal energy. Let’s now move on to a 4th - **chemical energy**.

As we noted earlier… burning a match yields about 1 BTU of thermal energy.

1 BTU of energy in turn is equivalent to about 780 foot-pounds of mechanical energy, which seems like quite a bit.

Now, we want to understand what form the energy had before it was released by the process of combustion? We’ve called this chemical energy. What is chemical energy?

This is clearly important, since all the energy stored in fossil fuels is chemical energy.

Read chapter 6
Chemical energy is the energy associated with atoms and with bonds between atoms... So, we need to focus on atoms.

Atoms are the building blocks of all matter... the negatively charged electrons of an atom orbit around the positively charged atomic nucleus.

The atomic nucleus itself is built out of some numbers of positively charged protons and neutrons (so named because they are electrically neutral).

The like charged protons repel each other. They are held together by the “strong force”. More about this when we discuss nuclear energy.

Chemical energy is associated with the orbits of the electrons.
Atoms are classified according to how many protons are in the nucleus. This is called the **atomic number**. There are then an equal number of orbiting electrons. The periodic table arranges all the atomic elements...
Start by focusing on hydrogen. Hydrogen is the most abundant element in the universe - 75% of ordinary matter by mass. Stars (at least young ones) are made primarily of hydrogen.

Hydrogen is the simplest atom, having just one proton & one electron.

From classical physics one can determine a radius and corresponding energy for the orbit of the electron around the proton…

But there is something very wrong with this picture….

When a charged particle, like an electron, accelerates (which a particle going around in a circle does), it is supposed to radiate. It should emit light. The light carries away energy and the electron must lose energy and spiral into the proton.

According to classical physics, atoms should be highly unstable….but we know that they are not.
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 ground state energy of a hydrogen atom is

\[ E = -13.6 \text{ eV} \]

Electron volts - yet another unit of energy

1 eV = 1.6 x 10^{-19} Joules

This is a very small energy, but we usually deal with huge numbers of atoms.

The energy is negative because the electron is bound to the proton. It would have to absorb a photon with energy greater than 13.6 eV to be knocked loose. Bound states always have negative energy.
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.