Course Preview: the Big Picture

- We use *a heck of a lot* of energy
  - primitive society uses < 100 W of power per person
  - our modern society burns 10,000 W per person
  - surely not in our homes! Where is this going on?
- Energy availability has enabled us to focus on higher-level issues as a society
  - art
  - science
  - home shopping network
• Long ago, almost all of our energy came from food (delivering muscle power), and almost all our energy went into securing food for ourselves
• Enter the work animal, supplementing our muscle power and enabling larger-scale agriculture
• Next burn wood to run boilers, trains
• 150 years ago, muscular effort and firewood provided most of our energy—and today this is less than 1% of the story
• Today, much more energy goes into growing/harvesting food than comes out of food!
• Today in US 86% of our energy comes from fossil fuels (oil, natural gas, coal)

Fuzzy on the concept of energy?

• Don’t worry—we’ll cover that.
A note on graphs: log vs. linear

- Many graphs are on logarithmic scales; watch for this!
- This condenses wide-ranging information into a compact area
- Pay attention, because you could warp your intuition if you don’t appreciate the scale
- Log scales work in factors of ten
- A given vertical span represents a constant ratio (e.g., factor of ten, factor of two, etc.)
- An exponential increase looks like a straight line on a logarithmic scale
Example Plots

Exponential plot is curved on linear scale, and straight on a logarithmic scale
A brief history of fossil fuels

- Here today, gone tomorrow
- What will our future hold?
  - Will it be back to a simple life?
  - Or will we find new ways to produce all the energy we want?
  - Or will it be somewhere in the middle

<table>
<thead>
<tr>
<th>Source</th>
<th>$10^{18}$ Joules/yr (~QBtu/yr)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum*</td>
<td>158</td>
<td>40.0</td>
</tr>
<tr>
<td>Coal*</td>
<td>92</td>
<td>23.2</td>
</tr>
<tr>
<td>Natural Gas*</td>
<td>89</td>
<td>22.5</td>
</tr>
<tr>
<td>Hydroelectric*</td>
<td>28.7</td>
<td>7.2</td>
</tr>
<tr>
<td>Nuclear Energy</td>
<td>26</td>
<td>6.6</td>
</tr>
<tr>
<td>Biomass (burning)*</td>
<td>1.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.5</td>
<td>0.13</td>
</tr>
<tr>
<td>Wind*</td>
<td>0.13</td>
<td>0.03</td>
</tr>
<tr>
<td>Solar Direct*</td>
<td>0.03</td>
<td>0.008</td>
</tr>
<tr>
<td>Sun Abs. by Earth*</td>
<td>2,000,000</td>
<td>then radiated</td>
</tr>
</tbody>
</table>

Global Energy: Where Does it Come From?

* Ultimately derived from our sun

Courtesy David Bodansky (UW)

Figure 1.6 Energy flow in the United States in 2002 in units of QHm, arranged to separate out useful energy from lost energy. (Source: Lawrence Livermore National Laboratory (2004) and United States Energy Information Administration, Annual Energy Review 2002.)
Why do we use so much energy?
World Population: 1950-2050

Source: U.S. Census Bureau, International Data Base, September 2004 version.
We live in a special time and place…

- We use almost 100 times the amount used by the rest of the world (by population)
- This phase has only lasted for the last century or so
- Most of our resources come from fossil fuels presently, and this has a short, finite lifetime
- Fossil fuels formed from solar energy over 300 million years, will be used up in a few centuries!
Energy: the capacity to do work

• This notion makes sense even in a colloquial context:
  – hard to get work done when you’re wiped out (low on energy)
  – work makes you tired: you’ve used up energy
• But we can make this definition of energy much more precise by specifying exactly what we mean by work

Work = Energy: more than just unpleasant tasks

• In physics, the definition of work is the application of a force through a distance; Energy is needed to do it

\[
W = F \cdot d
\]

• \( W \) is the work done = energy used
• \( F \) is the force applied
• \( d \) is the distance through which the force acts
• Only the force that acts in the direction of motion counts towards work
Okay, what is Force, then

- Force is a pushing/pulling agent
- Examples:
  - gravity exerts a downward force on you
  - the floor exerts an upward force on a ball during its bounce
  - a car seat exerts a forward force on your body when you accelerate forward from a stop
  - the seat you’re sitting in now is exerting an upward force on you (can you feel it?)
  - you exert a sideways force on a couch that you slide across the floor
  - a string exerts a centrally-directed (centripetal) force on a rock at the end of a string that you’re twirling over your head
  - the expanding gas in your car’s cylinder exerts a force against the piston

Forces have Direction

- In all the previous examples, force had a direction associated with it
- If multiple forces act on an object, they could potentially add or cancel, depending on direction

![Forces Add](image1.png)

![Forces Cancel](image2.png)
When net force is not zero

- When an object experiences a non-zero net force, it must accelerate
- Newton’s second law:
  \[ F = m \cdot a \quad \text{Force} = \text{mass times acceleration} \]
- The same force makes a small object accelerate more than it would a more massive object
  - hit a golf ball and a bowling ball with a golf club and see what happens

Question

A 150 lb person is standing still on the edge of a cliff. What is the total force on the person?

- A. zero
- B. 150 lb
- C. Can’t say from this info
Question

- A 150 lb person jumps (or was he pushed?) off a cliff and is falling to their death. What is the total force on the person?

A. zero  
B. 150 lb  
C. Can’t say from this info

But what is acceleration?

- This is getting to be like the “hole in the bucket” song, but we’re almost there…
- Acceleration is any change in velocity (speed and/or direction of motion)
- Measured as rate of change of velocity  
  – velocity is expressed in meters per second (m/s)  
  – acceleration is meters per second per second \(\text{per second}\)  
  – expressed as m/s\(^2\) (meters per second-squared)
Putting it back together: Units of Energy

- Force is a mass times an acceleration \((F=ma)\)
  - mass has units of kilograms
  - acceleration is \(m/s^2\)
  - force is then \(kg \cdot m/s^2\), which we call Newtons (N)
- Work is a force times a distance \((W=Fd)\)
  - units are then \((kg \cdot m/s^2) \cdot m = kg \cdot m^2/s^2 = N \cdot m = \text{Joules (J)}\)
  - One joule is one Newton of force acting through one meter
  - Imperial units of force and distance are pounds and feet, so unit of energy is foot-pound, which equals 1.36 J
- Energy has the same units as work: Joules

A Zoo of Units

- The main metric unit of energy is the **Joule**, and most of the world uses this, but many others exist:
  - The calorie is 4.184 Joules
    - raise 1 gram (c.c.) of water one degree Celsius
  - The Calorie (kilocalorie) is 4,184 J (used for food energy)
    - raise 1 kg (1 liter) of water one degree Celsius
  - The Btu (British thermal unit) is 1,055 J (roughly 1 kJ) or about 1/4 Calorie, or chemical energy of one match
    - raise 1 pound of water one degree Fahrenheit
  - The kilowatt-hour (kWh) is 3,600,000 J = 3600 kJ or 860 Calories (used for electrical energy)
    - one Watt (W) is one Joule per second
    - a kWh is 1,000 W for one hour (3,600 seconds)
  - Can also use “barrel of oil”, “ton of coal”, 1000 cubic feet of natural gas, gram of Uranium, or amount of any energy containing source, etc.
ENERGY CONVERSION FACTORS

- 1 kWh = 862 Cal = 3413 Btu = 3.6 MJ
- 1 Cal = .0016 kWh = 3.97 Btu = 4184 J
- 1 Btu = .252 Cal = .000293 kWh = 1055 J
- 1 ft-lb = 1.36 J
- 1 gal gasoline = 31000 Cal = 36.6 kWh = 125000 Btu = 132 MJ
- 1 bbl oil = 1.5M Cal = 5.8 M Btu = 1700 kWh = 6.1 GJ
- 1000 cf nat gas = 260,000 Cal = 1M Btu = 300 kWh = 1GJ
- 1 ton coal = 6.7M Cal = 27 M Btu = 7800 kWh = 28GJ
- 1 Qbtu = 300 G kWh = .17 G boe

POWER = ENERGY/TIME CONVERSIONS:

- 100 Qbtu/yr = 3.35 TW = 172. G boe/year
- 1 Cal/hr = 1.16 W = 3.97 Btu/hr
- 1 horsepower = 746W = 550 ft-lb/sec

boe = barrel of oil equivalent, Cal = kcal = 1000 cal, J=Joule (metric), kWh = kilo Watt hr, W = Watt (metric)

k=kilo, M=Mega=10^6, G=Giga=10^9, T=Tera=10^12, P=Peta=Q=Quadrillion=10^15

The Physics of Energy Formula List

- Lots of forms of energy coming fast and furious, but to put it in perspective, here’s a list of formulas:

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<td>$E = mgh \ (\text{mass times height times} \ 10\text{m/s}^2)$</td>
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Kinetic Energy

- Kinetic Energy: the energy of motion
- Moving things carry energy in the amount:
  \[ K.E. = \frac{1}{2}mv^2 \]
- Note the \( v^2 \) dependence—this is why:
  - a car at 60 mph is 4 times more dangerous than a car at 30 mph
  - hurricane-force winds at 100 mph are much more destructive (4 times) than 50 mph gale-force winds
  - a bullet shot from a gun is at least 100 times as destructive as a thrown bullet, even if you can throw it a tenth as fast as you could shoot it

Numerical examples of kinetic energy

- A baseball (mass is 0.145 kg = 145 g) moving at 30 m/s (67 mph) has kinetic energy:
  \[
  K.E. = \frac{1}{2} \times (0.145 \text{ kg}) \times (30 \text{ m/s})^2 \\
  = 65.25 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 65 \text{ J} = 0.016 \text{ Calories!}
  \]
- A quarter (mass = 0.00567 kg = 5.67 g) flipped about four feet into the air has a speed on reaching your hand of about 5 m/s. The kinetic energy is:
  \[
  K.E. = \frac{1}{2} \times (0.00567 \text{ kg}) \times (5 \text{ m/s})^2 \\
  = 0.07 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 0.07 \text{ J}
  \]
More numerical examples

• A 1500 kg car moves down the freeway at 30 m/s (67 mph)
  \[
  \text{K.E.} = \frac{1}{2} \times (1500 \text{ kg}) \times (30 \text{ m/s})^2
  = 675,000 \text{ kg}\cdot\text{m}^2/\text{s}^2 = 675 \text{ kJ}
  \]
Convert to Calories: 4.184 kJ = 1 Calorie
675 kJ (1 Calorie/4.184 kJ) = 161 Calorie

• A 2 kg (~4.4 lb) fish jumps out of the water with a speed of 1 m/s (2.2 mph)
  \[
  \text{K.E.} = \frac{1}{2} \times (2 \text{ kg}) \times (1 \text{ m/s})^2
  = 1 \text{ kg}\cdot\text{m}^2/\text{s}^2 = 1 \text{ J}
  \]

Question

1 m/s = 2.2 mph

◆ Kinetic energy is \( E = \frac{1}{2} m v^2 \). Which has more energy?

- A. 10 kg object going 100 m/s
- B. 100 kg object going 10 m/s
- C. 1 kg object going 1000 m/s
- D. 1000 kg object going 1 m/s
Gravitational Potential Energy

- It takes work to lift a mass against the pull (force) of gravity
- The force of gravity is \( mg \), where \( m \) is the mass, and \( g \) is the gravitational acceleration
  \[ F = mg \] (note similarity to \( F = ma \))
  - \( g = 9.8 \text{ m/s}^2 \) on the surface of the earth; or \( 32 \text{ ft/s}^2 \)
- Lifting a height \( h \) against the gravitational force requires an energy input (work) of:
  \[ \Delta E = W = F \cdot h = mgh \]
- Rolling a boulder up a hill and perching it on the edge of a cliff gives it gravitational potential energy that can be later released when the roadrunner is down below.
- Water in river or hydroelectric plant is using potential energy that it got from being lifted up when Sun (solar energy) evaporated the water

Question

- Potential energy is \( E = 10 \text{ m h (metric units)} \). Which has more energy?
  - A. 1 ton of water at a height of 100 ft
  - B. 100 tons of water at a height of 1 ft
  - C. 200 lb (1/10 ton) of water at 1000 ft
  - D. All of the above have same energy
First Example of Energy Exchange

- When the boulder falls off the cliff, it picks up speed, and therefore gains kinetic energy
- Where does this energy come from??
  \[ \Rightarrow \text{from the gravitational potential energy} \]
- The higher the cliff, the more kinetic energy the boulder will have when it reaches the ground

\[ \text{Energy is conserved, so} \quad \frac{1}{2}mv^2 = mgh \]

Can even figure out \( v \), since \( v^2 = 2gh \)

Examples of Gravitational Potential Energy

- How much gravitational potential energy does a 70 kg high-diver have on the 10 meter platform?
  \[ mgh = (70 \text{ kg}) \times (10 \text{ m/s}^2) \times (10 \text{ m}) \]
  \[ = 7,000 \text{ kg-m}^2/\text{s}^2 = 7 \text{ kJ} \]
  
  7 kJ (1 Calorie/4.182kJ) = 1.6 Calories
  
  This is amount of energy the diver used in climbing the stairs (actually more than this since some energy was wasted) They got that energy from the food they ate.
The Energy of Heat

• Hot things have more energy than their cold counterparts

• Heat is really just kinetic energy on microscopic scales: the vibration or otherwise fast motion of individual atoms/molecules
  – Even though it’s kinetic energy, it’s hard to derive the same useful work out of it because the motions are random

• Heat is frequently quantified by calories (or Btu)
  – One calorie (4.184 J) raises one gram of H₂O 1°C
  – One Calorie (4184 J) raises one kilogram of H₂O 1°C
  – One Btu (1055 J) raises one pound of H₂O 1°F

Energy of Heat, continued

• Food Calories are with the “big” C, or kilocalories (kcal)

• Since water has a density of one gram per cubic centimeter, 1 cal heats 1 c.c. of water 1°C, and likewise, 1 kcal (Calorie) heats one liter of water 1°C. In British Units, 1 Btu heats 1 pound of water 1 degree Fahrenheit.
  – these are useful numbers to hang onto

• Example: to heat a 2-liter bottle of Coke from the 5°C refrigerator temperature to 20°C room temperature requires 30 Calories, or 122.5 kJ

• Drink a pint (16 oz) of ice cold water (or coke). It weighs about 1 pound. To heat it to body temperature (98.6 degrees minus 32 degrees or change of 66.6 degrees. Takes about 67 Btu.

  Convert to Calories: 1 Calorie = 1kJ = 4 Btu, so

  67 Btu (1 Calorie / 4 Btu) = 16.75 Calories. Since 16 oz of coke has 210 Calories and about 17 Calories are used just heating to your body temp you get less calories drinking it cold! (or drinking quart of cold water “burns” 17 Calories).
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Heat Capacity

- Different materials have different capacities to hold heat
  - Add the same energy to different materials, and you’ll get different temperature rises
  - Quantified as heat capacity
  - Water is exceptional, with 4,184 J/kg/°C
  - Most materials are about 1,000 J/kg/°C (including wood, air, metals)

- Example: to add 10°C to a room 3 meters on a side (cubic), how much energy do we need?
  - air density is 1.3 kg/m\(^3\), and we have 27 m\(^3\), so 35 kg of air; and we need 1000 J per kg per °C, so we end up needing 350,000 J (= 83.6 Cal)
  - Important in designing solar heated houses! Also reason it is cooler near the coast than inland!
Power

- Power is simply energy exchanged per unit time, or how fast you get work done (Watts = Joules/sec)
- One horsepower = 745 W
- Perform 100 J of work in 1 s, and call it 100 W
- Run upstairs, raising your 70 kg (700 N) mass 3 m (2,100 J) in 3 seconds → 700 W output!
- Shuttle puts out a few GW (gigawatts, or $10^9$ W) of power!
- A big electrical power plant puts out around a GW. That is 1 Billion Joules per second. House takes a few kW (kilowatt)

Question

1 Calorie/minute = ? Watts

- Power is Energy used per second. $P = \text{energy/time}$. Which highest power?
  - A. Using 100 Calories in 10 minutes
  - B. Using 1000 Calories in 100 minutes
  - C. Using 10 Calories in 1 minute
  - D. Using 1 Calorie in 6 seconds
  - E. All of the above are the same power usage
Wind Energy

- Wind can be used as a source of energy (windmills, sailing ships, etc.)
- Really just kinetic energy
- Example: wind passing through a square meter at 8 meters per second
  - Each second we have 8 cubic meters
  - Air has density of 1.3 kg/m$^3$, so $(8 \text{ m}^3) \times (1.3 \text{ kg/m}^3) = 10.4 \text{ kg}$ of air each second
  - \( \frac{1}{2}mv^2 = \frac{1}{2} \times (10.4 \text{ kg}) \times (8 \text{ m/s})^2 = 333 \text{ J} \)
  - 333 J every second \( \rightarrow \) 333 Watts of available power per square meter (but to get all of it, you’d have to stop the wind)
- Stronger winds \( \rightarrow \) more power (like \( v^2 \))

Chemical Energy

- Electrostatic energy (associated with charged particles, like electrons) is stored in the chemical bonds of substances, e.g. carbohydrates, hydrocarbons
- Rearranging these bonds can release energy (some reactions require energy to be put in)
- Typical numbers are 100–200 kJ per mole
  - a mole is \( 6.022 \times 10^{23} \) molecules/particles
  - typical molecules are tens of grams per mole \( \rightarrow \) works out to typical numbers like several thousand Joules per gram, or a few Calories per gram (remember, 1 Cal = 1 kcal = 4187 J)
Chemical Energy Examples

• Burning a wooden match releases about one Btu, or 1055 Joules (a match is about 0.3 grams), so this is >3,000 J/g, nearly 1 Cal/g (450 Cal/lb)
• Burning coal releases about 20 kJ per gram of chemical energy, or roughly 5 Cal/g (2300 Cal/lb)
• Burning gasoline yields about 39 kJ per gram, or just over 9 Cal/g (4000 Cal/lb)
• Very few substances over about 11 Cal/g
• (1 Cal/g = 453 Cal/lb)

Energy from Food

• We get the energy to do the things we do out of food (stored solar energy in the form of chemical energy).
• Energy sources recognized by our digestive systems:
  – Carbohydrates: 4 Calories per gram
  – Proteins: 4 Calories per gram
  – Fats: 9 Calories per gram (like gasoline) (9 is more than 4, so gain more weight eating same amount of fat than carbs or protein!)
  – Roughly 3500 Calories/pound in your body fat! Less in your protein (muscle, skin, etc.)
Our Human Energy Budget

• A 2000 Calorie per day diet means 2000×4184 J = 8,368,000 J per day
• 8.37 MJ in (24 hr/day) × (60 min/hr)×(60 sec/min) = 86,400 sec corresponds to 97 Watts of power
• Even a couch-potato at 1500 Cal/day burns 75 W
• More active lifestyles require greater Caloric intake (more energy)

Nutrition Labels

• Nutrition labels tell you about the energy content of food
• Note they use Calories with capitol C
• Conversions: Fat: 9 Cal/g
               Carbs: 4 Cal/g
               Protein: 4 Cal/g
• This product has 72 Cal from fat, 48 Cal from carbohydrates, and 32 Cal from protein
  – sum is 152 Calories: compare to label
• 152 Cal = 636 kJ: enough to climb about 1000 meters (64 kg person)
• 1kwh = 860 Cal or about 1/4 lb body fat
• 1 gal of gas has 31,000 Calories
Mass-energy

- Einstein’s famous relation:
  \[ E = mc^2 \]
  relates mass to energy
- In effect, they are the same thing
  - one can be transformed into the other
  - physicists speak generally of mass-energy
- Seldom experienced in daily life directly
  - Happens at large scale in the center of the sun, and in nuclear bombs and reactors
  - Actually does happen at barely detectable level in all energy transactions, but the effect is tiny!

\[ E = mc^2 \] Examples

- The energy equivalent of one gram of material (any composition!!) is \((0.001 \text{ kg}) \times (3.0 \times 10^8 \text{ m/s})^2\)
  \[ = 9.0 \times 10^{13} \text{ J} = 90,000,000,000,000 \text{ J} = 90 \text{ TJ} \]
  - Man, that’s big!
  - Our global energy budget is equivalent to 1000 kg/yr (that’s about 1 ton per year)
- If one gram of material undergoes a chemical reaction, losing about 9,000 J of energy, how much mass does it lose?
  \[ 9,000 \text{ J} = \Delta mc^2, \text{ so } \Delta m = 9,000/c^2 = 9 \times 10^3/9 \times 10^{16} \]
  \[ = 10^{-13} \text{ kg} \quad \text{(would we ever notice?)} \]
Solar Energy is Nuclear, Using $E = mc^2$

- Thermonuclear fusion reactions in the sun’s center
  - Sun is 16 million degrees Celsius in its center
  - Enough energy to ram protons together (despite mutual repulsion) and make deuterium, then helium
  - Reaction per atom 20 million times more energetic than chemical reactions, in general

4 protons:
mass = 4.029

$^4\text{He}$ nucleus:
mass = 4.0015

2 neutrinos, photons (light)

$E = mc^2$ in Sun

- Helium nucleus is lighter than the four protons!
- Mass difference is 4.029 - 4.0015 = 0.0276 a.m.u.
  - 1 a.m.u. (atomic mass unit) is $1.6605 \times 10^{-27}$ kg
  - difference of $4.58 \times 10^{-29}$ kg
  - multiply by $c^2$ to get $4.12 \times 10^{-12}$ J
  - 1 mole ($6.022 \times 10^{23}$ particles) of protons $\rightarrow 2.5 \times 10^{12}$ J
  - typical chemical reactions are 100-200 kJ/mole
  - nuclear fusion is ~20 million times more potent stuff!
  - Nuclear fusion is energy source of hydrogen bomb
Energy from Light

- The tremendous energy from the sun is released as light. So light carries energy.
- Light is one form of electromagnetic radiation: radio, microwave, infrared, visible light, ultra-violet, X-ray, gamma ray radiation
- Wiggling electrons create EM radiation: the faster the wiggling, the more energy and the higher the frequency
- Best way to get actual amount of energy in light is using “blackbody” radiation, or thermal radiation…
- All objects emit “light”
- The color and intensity of the emitted radiation depend on the object’s temperature: hotter more radiation and color is “bluer”

Emitted Radiation’s Color and Intensity depend on Temperature

<table>
<thead>
<tr>
<th>Object</th>
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<th>Color</th>
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<tbody>
<tr>
<td>You</td>
<td>~ 30 C</td>
<td>Infrared (invisible)</td>
</tr>
<tr>
<td>Heat Lamp</td>
<td>~ 500 C</td>
<td>Dull red</td>
</tr>
<tr>
<td>Candle Flame</td>
<td>~ 1700 C</td>
<td>Dim orange</td>
</tr>
<tr>
<td>Bulb Filament</td>
<td>~ 2700 C</td>
<td>Yellow</td>
</tr>
<tr>
<td>Sun’s Surface</td>
<td>~ 5500 C</td>
<td>Brilliant white</td>
</tr>
<tr>
<td>Neutron Star</td>
<td>~ millions C</td>
<td>X-rays</td>
</tr>
<tr>
<td>Molecules in deep space</td>
<td>&lt; -272C</td>
<td>Microwave or radio</td>
</tr>
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The hotter it gets, the “bluer” the emitted light
The hotter it gets, the more intense the radiation (more energy)
“Blackbody”, or Planck Spectrum

Continuous spectra (thermal spectra) for different temperatures. At higher temperatures, there is more energy at all wavelengths and the peak of the spectrum shifts to smaller wavelengths (toward the blue side). Wien’s law: $\lambda_{\text{peak}} = \frac{299,792,458 \text{ m/s}}{T}$ (in K). Red stars or planets’ $\lambda_{\text{peak}}$ is used to measure their temperature. The Sun’s thermal spectrum ($5800 \text{ K}$) is shown for comparison. Star temperature range from $2000-40,000 \text{ K}$.

Same thing, on logarithmic scale:

Sun peaks in visible band (0.5 microns), light bulbs at 1 µm, we at 10 µm.

(note: $0^\circ \text{C} = 273^\circ \text{K}; 300^\circ \text{K} = 27^\circ \text{C} = 81^\circ \text{F}$)
Okay, but how much energy?

- The power given off of a surface in the form of light is proportional to the fourth power of temperature!
  
  \[ F = \sigma T^4 \] in Watts per square meter

  - the constant, \( \sigma \), is numerically \( 5.67 \times 10^{-8} \) W/K^4/m^2
  - easy to remember constant: 5678
  - temperature must be in Kelvin:
    - °K = °C + 273
    - °C = (5/9) \times (°F – 32)

- Example: radiation from your body:
  \[ (5.67 \times 10^{-8}) \times (310)^4 = 523 \text{ Watts per square meter} \]
  (if naked in the cold of space: don’t let this happen to you!)

Radiant Energy, continued

- Example: The sun is 5800°K on its surface, so:
  \[ F = \sigma T^4 = (5.67 \times 10^{-8}) \times (5800)^4 = 6.4 \times 10^7 \text{ W/m}^2 \]
  Summing over entire surface area of sun gives
  \[ 3.9 \times 10^{26} \text{ W} \]

- Compare to total capacity of energy production on earth: \( 3.3 \times 10^{12} \) W
  - Single power plant typically 0.5–1.0 GW (\( 10^9 \) W)

- In earthly situations, radiated power out partially balanced by radiated power in from other sources
  - Not 523 W/m^2 in 70°F room, more like 100 W/m^2
    - goes like \( \sigma T_h^4 - \sigma T_c^4 \)
Electrical Energy

- Opposite charges attract, so electrons are attracted to protons. This holds atoms together.
- It takes energy to pull electrons off their atoms.
- Electrons want to get back home to their protons. They can only travel through conductors like wires, not through insulators like plastic, paper or wood. They will go through miles of wire to get home to their protons!
- This is how electricity works. The electron’s energy can be stolen as it goes home. Can be used in many, many ways.
- Note electricity is not a primary source of energy. Energy (from burning coal, nat gas, from hydro, wind, nuke or solar) is used to pull of electrons and that energy can be moved through wires and got back at will.

And those are the major players…

- We’ve now seen most of the major energy players:
  - work as force times distance
  - kinetic energy (wind, ocean currents)
  - gravitational potential energy (hydroelectric, tidal)
  - chemical energy (fossil fuels, batteries, food, biomass)
  - heat energy (power plants, space heating)
  - mass-energy (nuclear sources, sun’s energy)
  - radiant energy (solar energy)
  - electrical energy (energy of electrons separated from their atoms)
Conservation and Exchange of Energy
Nothing Comes for Free

Energy is Conserved

- **Conservation of Energy** is different from Energy Conservation, the latter being about using energy wisely.
- Conservation of Energy means energy is *neither created nor destroyed*. The amount of energy in the Universe is *constant*!!
- Don’t we *create* energy at a power plant?
  - Oh that this were true—no, we simply *transform* energy at our power plants.
- Doesn’t the sun *create* energy?
  - Nope—it *exchanges* mass for energy.
- Don’t batteries give us new energy?
  - Nope, just convert stored chemical energy to electrical energy. Someone had to put that energy in there.
Energy Exchange

- Though the total energy of a system is constant, the *form* of the energy can change
- A simple example is that of a simple pendulum, in which a continual exchange goes on between kinetic and potential energy

![Pendulum diagram](pivot)

K.E. = 0; P. E. = \( mgh \)

Perpetual Motion

- Why won’t the pendulum swing forever?
- It’s hard to design a system free of energy paths
- The pendulum slows down by several mechanisms
  - Friction at the contact point: requires force to oppose; force acts through distance → work is done
  - Air resistance: must push through air with a force (through a distance) → work is done
  - Gets some air swirling: puts kinetic energy into air (not really fair to separate these last two)
- Perpetual motion means no loss of energy
  - solar system orbits come very close
Some Energy Chains:

- A coffee mug with some gravitational potential energy is dropped
- potential energy turns into kinetic energy
- kinetic energy of the mug goes into:
  - ripping the mug apart (chemical: breaking bonds)
  - sending the pieces flying (kinetic)
  - into sound
  - into heating the floor and pieces through friction as the pieces slide to a stop
- In the end, the room is slightly warmer (heated by exactly the number of Calories originally stored in the potential energy).

Gasoline Example

- Put gas in your car, containing 9 Cal/g (31,000 Cal/gallon)
- Combust gas, turning 9 Cal/g into kinetic energy of explosion
- Transfer kinetic energy of gas to piston to crankshaft to drive shaft to wheel to car as a whole
- That which doesn’t go into kinetic energy of the car goes into heating the engine block (and radiator water and surrounding air), and friction of transmission system (heat), and noise of engine (heating the air), etc.
- Much of energy goes into stirring the air (ends up as heat)
- Apply the brakes and convert kinetic energy into heat
- It all ends up as waste heat, ultimately
Bouncing Ball

- Superball has gravitational potential energy
- Drop the ball and this becomes kinetic energy
- Ball hits ground and compresses (force times distance), storing energy in the spring
- Ball releases this mechanically stored energy and it goes back into kinetic form (bounces up)
- Inefficiencies in “spring” end up heating the ball and the floor, and stirring the air a bit
- In the end, all is heat

Why don’t we get hotter and hotter

- If all these processes end up as heat, why aren’t we continually getting hotter?
- If earth retained all its heat, we would get hotter
- All of earth’s heat is radiated away
  \[ F = \sigma T^4 \]
- If we dump more power, the temperature goes up, the radiated power increases dramatically
  - comes to equilibrium: power dumped = power radiated
  - stable against perturbation: \( T \) tracks power budget
Rough numbers

- How much power does the earth radiate?
  \[ F = \sigma T^4 \]
  for \( T = 288^\circ \text{K} = 15^\circ \text{C} \) is 390 W/m\(^2\)
- Summed over entire surface area (\(4\pi R^2\), where \(R = 6,378,000\) meters) is 2.0×10\(^{17}\) W
- Human global production is about 13×10\(^{12}\) W
  (100 QBtu/yr = 3.3TW, World ~4 times more)
- Solar radiation incident on earth is 1.8×10\(^{17}\) W
  – just solar luminosity of 3.9×10\(^{26}\) W divided by geometrical fraction that points at earth
- Amazing coincidence of numbers! (or is it…)

No Energy for Free

- No matter what, you can’t create energy out of nothing: it has to come from somewhere
- We can transform energy from one form to another; we can store energy, we can utilize energy being conveyed from natural sources
- The net energy of the entire Universe is constant
- The best we can do is scrape up some useful crumbs
Examples

• Unit conversion:
  – 100 Btu into Calories: 100 Btu (1 Calorie/3.96 Btu) = 25 Cal
  – 100 Btu into Joules: 100Btu (1055 J/1 Btu) = 105,500 J = 1 x 10^5 J
  – 100 Btu into kWh: 100Btu (1 kWh / 3413 Btu) = 0.029 kWh
  – 10 gallons of gasoline into kWh: 10 gals (132,000,000 J/1 gal) (1 kWh/3,600,000 J) = 366 kWh
  – How many calories per hour does 100 W bulb use? 100 W = 100 Joule/sec (1 Cal/4184 J) (60 sec/1 min) (60 min/1 hour) = 86 Calories/hour. About what average person eats!
  – Gasoline is $3/gal. Electricity if $0.15/kWh. Which is more expensive? Convert $3/gal to $ per kWh. $3/gal (1 gal/36.6 kWh) = $0.08/kWh for gasoline. Gasoline is cheap in the USA!

Examples

• Power vs. Energy: (P=E/time; E = P t; t = E/P)
  – Car goes 60 miles in one hour and uses 3 gal of gas. What was total power in Watts? P=E/t, Power = (3 gal/1 hour) = 3gal/hr (36.6 kWhr / 1 gal) = 109 kW (1000W / 1 kW) = 109,000 W
    [Alternative method: 3 gal/hr (132,000,000 J/1 gal) (1 hr/3600 sec) = 110,000 J/sec = 110,000 W
  – 1000 W space heater is on for 3 hours. How much does it cost if electricity is $.15/kWh? E= P t. E = (1000 W)(3 hr) = 3000 W hr (1kW/1000W) = 3kWh ($0.15/kWh) = $0.45 [Alternative method: E = (1000 W)(3 hr) (3600 sec/hr) = 10,800,000 Ws = 10,800,000 J (1 kWh/3,600,000J) = 3 kWh. Again 45 cents.
  – AAA Battery contains 3.3 Calories of chemical energy. How long can it run a 2 Watt light bulb? time = E/P. time = 3.3 Calories/2 W = 1.65 Cal sec/Joule (4184 J/1 Cal) = 6,900 seconds (1 hr/3600 sec) = 1.9 hours
Participation Questions
(write on piece of paper with name and hand in)

The U.S. uses about 7 Gbarrels of oil each year. This could be converted into which of the following units?

- A. Joules
- B. Watts
- C. QBtu's
- D. Dollars $
- E. Any of the above

Participation Question

If one barrel of oil contains 1700 kWh of energy, how many Watts is 7 Gbarrel/year?

- A. 1400 GW (Giga Watts)
- B. 1.4 GW
- C. 11,900 W
- D. 11.9 MW
- E. $1 \times 10^{11}$ W
Participation Question

- If the total yearly oil use in the U.S. is about 1400 GW, how many 1000 MW nuclear reactors will need to be built to replace all oil use with electricity?

A. A little more than one will be needed
B. Around 14
C. Around 140
D. Around 1400
E. Can’t convert Watts to reactors; power vs energy

More Power Examples

- How much power does it take to lift 10 kg up 2 meters in 2 seconds?
  \[ mg \cdot h = (10 \text{ kg}) \times (10 \text{ m/s}^2) \times (2 \text{ m}) = 200 \text{ J} \]
  
  200 J in 2 seconds \(\rightarrow\) 100 Watts

- If you want to heat the 3 m cubic room by 10°C with a 1000 W space heater, how long will it take?
  
  We know from before that the room needs to have 360,000 J added to it, so at 1000 W = 1000 J/s this will take 360 seconds, or six minutes.

  But: the walls need to be warmed up too, so it will actually take longer (and depends on quality of insulation, etc.)
A note on arithmetic of units

- You should carry units in your calculations and multiply and divide them as if they were numbers.
- Example: the force of air drag is given by:
  \[ \text{F}_{\text{drag}} = \frac{1}{2} \text{cD} \text{rAv}^2 \]
- \text{cD} is a dimensionless drag coefficient.
- \text{r} is the density of air, 1.3 kg/m\(^3\).
- \text{A} is the cross-sectional area of the body in m\(^2\).
- \text{v} is the velocity in m/s.
- units: (kg/m\(^3\))·(m\(^2\))·(m/s\(^2\)) = (kg·m\(^2\)/m\(^3\))·(m\(^2\)/s\(^2\)) = kg·m/s\(^2\) = Newtons

ENERGY CONVERSION FACTORS

- 1 kWh = 862 Cal = 3413 Btu = 3.6 MJ
- 1 Cal = .0016 kWh = 3.97 Btu = 4184 J
- 1 Btu = .252 Cal = .000293 kWh = 1055 J
- 1 ft-lb = 1.36 J
- 1 gal gasoline = 31000 Cal = 36.6 kWh = 125000 Btu = 132 MJ
- 1 bbl oil = 1.5M Cal = 5.8 M Btu = 1700 kWh = 6.1 GJ
- 1000 cf nat gas = 260,000 Cal = 1M Btu = 300 kWh = 10 GJ
- 1 ton coal = 6.7M Cal = 27 M Btu = 7800 kWh = 28 GJ
- 1 Qbtu = 2940000 Cal = 13M Btu = 13000 kWh = 47 GJ
- \text{boe} = \text{barrel of oil equivalent}, \text{Cal} = \text{kcal} = 1000 \text{ cal}, \text{J}=\text{Joule (metric)}, \text{kWh} = \text{kilo Watt hr}, \text{W} = \text{Watt (metric)}
- k=kilo, M=Mega=10\(^6\), G=Giga=10\(^9\), T=Tera=10\(^12\), P=Peta=Q=Quadrillion=10\(^15\)