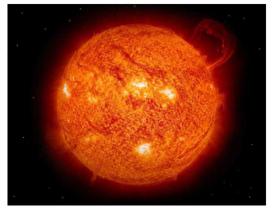




Forms of Energy II

Wind, Chemical, Food, Mass-energy, Light

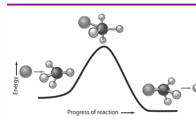
The Physics 12 Formula List

- Lots of forms of energy coming fast and furious, but to put it in perspective, here's a list of formulas that you'll need to use:

Relation Type	**Formula**
Work as force times distance	$W = F \cdot d$
Kinetic Energy	K.E. = $\frac{1}{2}mv^2$
(Grav.) Potential Energy	$E = mgh$
Heat Content	$\Delta E = c_p m \Delta T$
Power	$P = \Delta E / \Delta t$
Mass-energy	$E = mc^2$
Radiative Flux	$F = \sigma T^4$

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 m^3)×(1.3 kg/m^3) = 10.4 kg of air each second
  - $\frac{1}{2}mv^2 = \frac{1}{2} \times (10.4 \text{ kg}) \times (8 \text{ m/s})^2 = 333$ J
  - 333 J every second → 333 Watts of available power per square meter (but to get *all* of it, you'd have to stop the wind)
- Stronger winds → more power (like v^3)



Chemical Energy

- Electrostatic energy (associated with charged particles, like electrons) is stored in the chemical bonds of substances.
- 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 6.022×10^{23} molecules/particles
  - typical molecules are tens of grams per mole→works out to typical numbers like several thousand Joules per gram, or a few kilocalories per gram (remember, 1 kcal = 4184 J)

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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 kcal/g
- Burning coal releases about 20 kJ per gram of chemical energy, or roughly 5 kcal/g
- Burning gasoline yields about 39 kJ per gram, or just over 9 kcal/g
- Very few substances over about 11 kcal/g

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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 kilocalories per gram
  - Proteins: 4 kilocalories per gram
  - Fats: 9 kilocalories per gram (like gasoline)

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Nutrition Labels

Whole Milk
Serving Size 8 fl oz (240mL)
Servings Per Container 2

Amount Per Serving	
Calories 150	Calories from Fat 70
	% Daily Value*
Total Fat 8g	12%
Saturated Fat 5g	25%
Cholesterol 35mg	12%
Sodium 125mg	5%
Total Carbohydrate 12g	4%
Dietary Fiber 0g	0%
Sugars 11g	
Protein 8g	

Vitamin A 6% • Vitamin C 4%
Calcium 30% • Iron 0% • Vitamin D 25%

* Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

- Nutrition labels tell you about the energy content of food
- Note that capital C means kcal
- Conversions: Fat: 9 kcal/g
  Carbs: 4 kcal/g
  Protein: 4 kcal/g
- This product has 72 kcal from fat, 48 kcal from carbohydrates, and 32 kcal from protein
  - sum is 152 kilocalories: compare to label
- 152 kcal = 636 kJ: enough to climb about 1000 meters (64 kg person)

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Our Human Energy Budget

- A 2000 kcal 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 kcal/day burns 75 W
- More active lifestyles require greater caloric intake (more energy)

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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

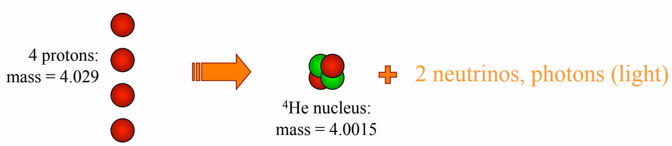
- The energy equivalent of one gram of material (*any composition!!*) is (0.001 kg)×(3.0×10^8 m/s)^2 = 9.0×10^{13} J = 90,000,000,000,000 J = 90 TJ
  - Man, that's big!
  - The U.S. energy budget is equivalent to 1000 kg/yr
- If one gram of material undergoes a *chemical* reaction, losing about 9,000 J of energy, how much *mass* does it lose?

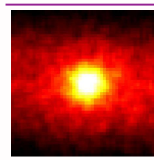
  9,000 J = Δmc^2, so Δm = 9,000/c^2 = 9×10^3/9×10^{16}

  = 10^{-13} kg (would we *ever* notice?)

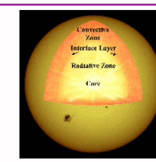
Solar Energy is Nuclear, Using $E = mc^2$

- 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





$E = mc^2$ 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 1.6605×10^{-27} kg
  - difference of 4.58×10^{-29} kg
  - multiply by c^2 to get 4.12×10^{-12} J
  - 1 mole (6.022×10^{23} particles) of protons → 2.5×10^{12} J
  - typical chemical reactions are 100-200 kJ/mole
  - nuclear fusion is ~20 million times more potent stuff!

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Energy from Light

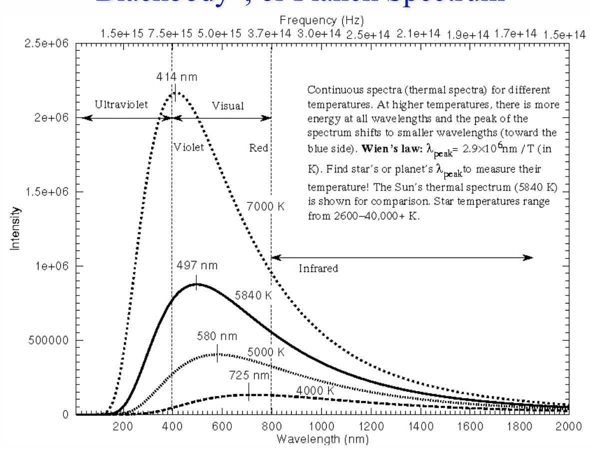
- The tremendous energy from the sun is released as light. So light carries energy.
- How much??
- Best way to get at this is through the process of "blackbody" radiation, or thermal radiation…
- All objects emit "light"
  - Though almost all the light *we* see is *reflected* light
- The color and intensity of the emitted radiation depend on the object's temperature

Emitted Radiation's Color and Intensity depend on Temperature

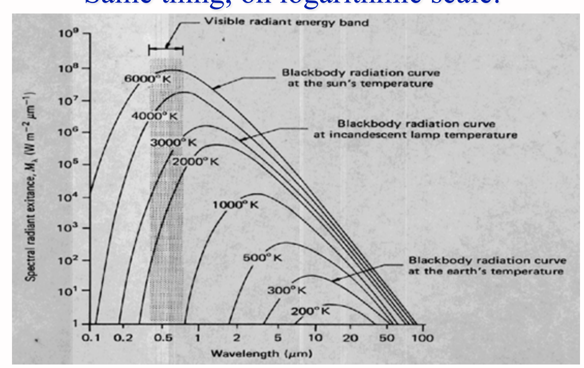
Object	Temperature	Color
You	~ 30 C	Infrared (invisible)
Heat Lamp	~ 500 C	Dull red
Candle Flame	~ 1700 C	Dim orange
Bulb Filament	~ 2700 C	Yellow
Sun's Surface	~ 5500 C	Brilliant white

The hotter it gets, the "bluer" the emitted light
The hotter it gets, the *more intense* the radiation (more energy)

"Blackbody", or Planck Spectrum



Same thing, on logarithmic scale:



Sun peaks in visible band (0.5 microns), light bulbs at 1 μm, we at 10 μm.
(note: 0°C = 273°K; 300°K = 27°C = 81°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, σ, is numerically 5.67×10^{-8} W/°K^4/m^2
  - easy to remember constant: 5678
  - temperature must be in Kelvin:
    - °K = °C + 273
    - °C = (5/9)×(°F –32)
- Example: radiation from your body:

  $(5.67\times10^{-8})\times(310)^4 = 523$ 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:

  $F = \sigma T^4 = (5.67\times10^{-8})\times(5800)^4 = 6.4\times10^7$ W/m^2

  Summing over entire surface area of sun gives

  3.9×10^{26} W
- Compare to total capacity of energy production on earth: 3.3×10^{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 $\sigma T_h^4 - \sigma T_c^4$

And those are the major players…

- We've now seen all the major energy players we'll be discussing in this class:
  - 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)

Assignments

- Homework #1 due April 12 in class:
  - Chapter 1 problems, plus online additions
    - see assignments link on web page for details
  - don't forget to show your work/reasoning on the multiple choice!
    - the answers alone do not suffice
- Quiz #1 due Friday, April 12, by midnight
  - TED will be up and quizzes available by Thursday
  - 3 attempts permitted
  - all numerical/quantitative this week