Reviewing for the final.

The final is on **Monday June 4 (note time: 8.30-10.20 in the classroom, MGH 242)**. It is closed-book, but you may bring a single sheet of paper with notes on both sides (not too microscopic please). Any formulas required will be given in a list at the end of the quiz sheet.

The final ‘quiz’ (I like the word better than ‘exam’) will start with some short questions (1.), then as in the midterm quiz, will have some questions from the science core (2.) and finally (3.) some short essay questions. You will choose a few of many questions in each section.

Some practice questions are below. The review questions for the mid-term are still relevant). **Note:** there is not very much here on chemical bonds, carbon cycle and photosynthesis, but we will hand out more review problems on this, this week.

### 1. Short Answers, 2 or 3 lines (will do 2 on final)

1.1 What was Operation Cat Drop of the British Royal Air Force? (Hawken/Lovins)
1.3 Where is Curitiba and what is its significance? (Hawkin/Lovins)
1.4 What differences between the oil deposits in Saudi Arabia and the US, which has economic importance [Roberts].
1.5 What is the significance of the specific heat capacity of a gas or liquid?
1.6 What are the principal animals hunted by natives of Greenland?
1.7 Explain why the flame of a candle has different colors in it.
1.8 Breaking apart water molecules and forming hydrogen gas and oxygen gas requires a net input of energy equal to 118 Kcal/mol, because the H-O bond in water is stronger than the H-H bond in hydrogen gas. Electrolysis is the use of electricity to do this. What kinds of forces are involved in this chemical energy?
1.9 Water is a great solvent: many solids will dissolve in it, meaning that their rigid bonds between atoms are broken as it interacts with the water molecule. What property of H₂O molecule is particularly important for this?
1.10 Name three factors which make the US demand for energy unresponsive to its cost

### 2. Questions from the science core (will do 2 on final).

2.1 Why is the Arctic, and Greenland in particular, very sensitive to global warming (the rising temperature of the Earth’s atmosphere and oceans)?

2.2 Compare the efficiencies of car and bicycle as people-transporters. An efficient bicyclist can ride 20 mph (32 km/hour) for long stretches, burning perhaps 400 Kcal (food calories) per hour. [1 Kcal = 4184 Joules] A typical car does 25 miles per gallon of gasoline, which is 10.65 km/liter. The energy content of gasoline is about 45 MJ/kg.
There quite a few interesting calculations possible here. The bicyclist burns \(400 \times 4184 = 1.6 \times 10^6\) Joules per hour going 32 km, or about \(0.5 \times 10^4\) J/km. The car does 10.65 km/liter and 1 liter of gasoline is a bit less than a kg (gasoline is 0.73 times as dense as water). So this gives 14.6 km/kg or turning it upside down, \(45 \times 10^3 J / 14.6\) km or \(3.1 \times 10^5\) J/km. So the bicycle is some 62 times as efficient as a car in moving a person. A daily diet of 2500 Kcal would be typical. Think in terms of candy bars, at 1 million J/candy bar (250 Kcal/candy bar). A daily diet would be (ugh) 10 candy bars. Some researchers find that decreasing caloric intake increases our lifespan, almost in proportion, as our life expectancy is a certain number of Kcals, more than a certain number of years (Gruber and Kalamas, Gerontology, 2000). Hmm, holiday eating is coming.

In class we estimated the power needed to ride a bicycle 4 different ways:

- by the fuel consumption of the rider (say, 1 candy bar per 20 km, above though this seems like too much candy bar)...need to account of efficiency of the body in converting candy to mechanical energy, roughly 20%.
- by the time it takes to coast to a stop (\(\Delta\) kinetic energy/\(\Delta\) time), reasoning that the forces of wind and friction that slow you down are the same ones you fight against when pedaling, so you can connect the two: 
  \[
  \text{power} = \text{force} \times \text{velocity} \quad \text{and force} = \frac{\Delta \text{(KE)}}{\Delta \text{(time)}}.
  \]
- by the rate you do work pushing on the pedals (force \times velocity, where you estimate force as some fraction of your body weight and remember that weight = mass \times g, the acceleration due to gravity; if 100 kg is a guy’s mass, he ‘weighs’ 980 Newtons)
- by the forces resisting the bicycle at steady speed, mostly wind (which we estimated as \(\frac{1}{2} C_D \rho V^2 A\) where \(\rho\) is air density, \(V\) is the speed, \(A\) is the frontal area of the cyclist... \(C_D\) is a fudge factor called the drag coefficient ranging from 0.2 to 0.9 or so, because you don’t take all the energy out of the airstream. It takes about 10 sec. to Google it on the web (‘drag coefficient cyclist’): visit [www.machinehead-software.co.uk/dragcalc.html](http://www.machinehead-software.co.uk/dragcalc.html).

2.3 Greenland is about 2500 km long and 1000 km wide. The ice cap peaks at 3 km above sea level, and holds about 10% of the Earth’s fresh water (Antarctic ice holds about 70% of the fresh water). If Greenland were to melt, roughly how much liquid water (in m\(^3\)) would be released, and how much would global sea level rise, on average? The area of the oceans is about \(3 \times 10^{14}\) m\(^2\). [radius of the Earth, \(R = 6400\) km, area of oceans = 70% of \(4\pi R^2\)]. What if Antarctica were to melt too?

2.4 The hydropower of the world, currently installed is 600,000 Mwatts = \(6 \times 10^{11}\) watts; the US has 160,000 Mwatts = \(1.5 \times 10^{11}\) watts. Calculate the fraction of the total energy utilization that these numbers represent. World: \(4 \times 10^{20}\) Joules per year; USA: \(1 \times 10^{20}\) Joules/year.

2.5 The new Airbus 330-220 burns about 8.5 tonnes of fuel per hour at its cruising speed of 900 km/hr. If that fuel contains \(40 \times 10^6\) Joules/kg of energy, how many watts of power does this rate of burning represent? 1 tonne = \(10^3\) kg. How does this fuel use compare with each of the 330 passengers driving a car that uses 10 kg/hour of gasoline, yet is going at only 100 km/hr?
2.6 In the ocean circulation water rich with oxygen sinks from the surface at $10^7$ m$^3$/sec, flows round the world and slowly rises back to the surface again. If the volume of the world’s oceans is $10^{18}$ m$^3$, how many years does it take, on average, for the water to return to the sea surface to ‘breathe’ again?

This is just a residence time calculation: flux of water (m$^3$/sec) x time (sec) = volume of water transported (m$^3$). So divide $10^{18}$ m$^3$/10$^7$ m$^3$/sec = 10$^{11}$ sec…or (because there are $\pi \times 10^7$ sec/year) about 3000 years. This assumes that as in the polluted lake, the incoming water is well-mixed round the oceans and not taking a short-cut back to the surface. In fact there seem to be such short-cuts and it is one of the big research questions in oceanography, to find them with willing, unsuspecting graduate students sent out to sea.

2.7 If the sun heats the top 10m of the ocean in spring, with a power of 200 watts/m$^3$, how many degrees warmer will it be after 3 months? The specific heat capacity of water is about 4000 J/kg 0°C and the density of water is about 10$^3$ kg/m$^3$.

Given that the greenhouse effect is adding about 2.5 watts/m$^2$ to the net heating of the Earth’s surface, how do you expect the oceans to affect the temperature change (compare a world with no oceans, with our world 70% covered by ocean).

Here the specific heat comes back again. If we call the heat input per kg $\Delta Q$, $\Delta Q (J/kg) = Cv \times \text{change in temperature, } \Delta T$.

The total heat input for a mass $M$ (kg) of water will be $M \Delta Q \text{ Joules}$, so

$$M \Delta Q = Cv \times \Delta T \times M,$$

Let’s consider one square meter of sea surface. Now the key step is to remember that 1 watt of power falling on this square meter = 1 J/sec … 200 watts= 200 J/sec (all this, for the 1 square meter of surface). Thus

$$M \Delta Q = 200 x t \text{ (J)}$$

for this 1 m$^2$ area, where $t$ is the time the sun shines (3 months). So use the above two equations,

$$200 \times t \text{ (Joules)} = Cv \times \Delta T \times M$$

or

$$\Delta T = \frac{200 \times t}{MCv}$$

The mass $M$ of this column of seawater, 10m tall and 1 m$^2$ in area, is $10^4$ kg.
The time $t$ is 3 months or $\frac{1}{4}$ year or $\pi/4 \times 10^7$ seconds. Putting in the numbers gives

$$\Delta T = 37.6 \degree C$$

Well that’s a lot of warming. What actually happens is that evaporation of the water takes some of the heat away, and so the ocean surface warms something like $\frac{1}{2}$ this much.

It may help in this kind or problem to use a logical sequence like:

1 watt falling on 1 square meter of sea surface will heat 1 kg of water by $1/4000$ of a degree C in 1 second.

So, it will heat $10^4$ kg of water $1/10^4$ as much: by $1/(4 \times 10^7)$ degrees in 1 second.

It will heat up $\pi/4 \times 10^7$ times this much in $\pi/4 \times 10^7$ seconds. Then 200 watts per m$^2$ will do 200 times as much heating. Same result.

2.8 The solar heating of the Earth changes with the seasons, in part because the Earth is closest to the sun in January, closer by about 3% than in July. What change in mean temperature of the Earth would this cause if the simple greenhouse model of the Earth were accurate? [Spherical Cow]

Our calculation showed that the temperature change varies like the $\frac{1}{4}$ power of the solar heating, $T$ is proportional to (heating)$^{1/4}$. 
Solar heating dies off with distance from the sun in proportion to the square of the distance, R. This is because the same amount of solar energy is flowing in all directions from the sun, as if it were passing through a spherical surface, whose area is $4\pi R^2$. Thus, heating is proportional to $R^{-2}$.

Together these give:

$$T \propto R^{-1/2}$$

So if $R$ increases by 3%, how will the square root of $R$ change? This is a bit of extra knowledge we have not talked about in class. The formula is that if a number changes by a small percent, say $P$ percent, its square root changes by $\frac{1}{2} P$. So the result is:

$$T \text{ will change by } 1.5 \% \text{ between summer and winter.}$$

2.9 Why do we dam rivers to generate hydroelectric power? To think about this calculate the energy flow (in watts) of a stream of water falling from a height $h$, of 100 m from a reservoir, with a flow rate $F_w$ (m$^3$/sec) ...(the water has negligible kinetic energy in the reservoir). Is this a useful power source for a river with flow rate $F_w = 10^3$ m$^3$/sec?

The potential energy per m$^3$ of water, due to the gravity force is $\rho gh$ where $\rho$ is the density of the water, $10^3$ kg/m$^3$ and $g = 9.8$ m/sec$^2$ is the acceleration due to gravity.

We showed that the flow of kinetic energy (KE) in a stream is:

$$KE \text{ per unit volume x water flow rate, } F_w$$

This is energy per unit time, or power. A falling object (like water in this case) has a velocity $\sqrt{2gh}$ in falling from a height $h$. Here $h = 100m$, $g = 9/8$ m/sec$^2$ so $V = 44$ m/sec. The KE per unit volume = density times $\frac{1}{2} V^2 = 0.97 \times 10^6$. Put this velocity in the above formula, the power is $10^3 \times 10^6$ watts.

which is huge...1000 megawatts. That’s because $F_w$ is huge, and we have ignored losses to friction.

3. Essays. Choose one from these topics and write a short essay...typically 2 pages of handwriting.

3.1. What do Lovins/Hawkens mean by “the present industrial system is, practically speaking, a couch potato”. Would Lomborg agree?

3.2 If global energy use of $4 \times 10^{20}$ Joules/year were cut by 90% (‘Factor Ten’) and distributed equally among the 6 billion citizens, how much ‘poorer’ would Americans be? Recall that energy cost is about 6% of Gross Domestic Product. What positive changes by our political and industrial leaders could help ease this transition? [This is quite a deep question, if followed through.]

3.3 What are some of the hidden costs of oil production and use, which make the price per barrel an imperfect measure? What would Lomborg say about these costs? What would Hawken/Lovins’ say about these costs?

3.4 With solar, wind, biomass and hydropower supplying only about 7% of our global energy use, write a paragraph describing a Utopian (positive, idealistic) image of life with just this supply of energy and no fossil fuels. Give at least one quantitative calculation (for example, based on your personal energy profile). What population migrations might result from this change in energy supply?

3.5 Environmentalists argue that building taller smokestacks cleaned up London’s polluted air and yet ‘exported the pollution to fall as acid rain in Scandinavia. Lomborg
*(The Skeptical Environmentalist)* argues that saving 64,000 lives per year by improving London’s air is more important than saving Scandinavian trees. What do you think?

3.6 “…the sense among governments was that oil was too important to be left in private hands.” [Roberts, *The End of Oil*]. Discuss with examples.
1. Short answers, 2 or 3 lines each; answer 2 of the following questions, with explanations:

1. Describe how thermal energy (‘heat’) moves when cold air flows out over the warm ocean in the Arctic?

2. We stir a cup of coffee to cool it off. If energy is conserved, shouldn’t our stirring work warm up the coffee?

3. Explain the colors seen in the flame of a burning candle.

4. If global energy use increases 2% per year, in roughly how many years will it double?

5. What property of water determines the distinctive shapes of ice crystals?

6. Why is moist air less dense than dry air at the same temperature and pressure?

2. Science-core questions: answer 2 of the following:

1. The Greenland ice cap is fed by precipitation. What keeps it in balance (approximately), so that it does not grow ever higher? If the precipitation is 1 m per year (of liquid water or snow equivalent to that much water), what is the average residence time for a molecule of water in the ice cap? The volume of the ice is roughly $3 \times 10^7$ km$^3$ and its surface area is about $1.7 \times 10^6$ km$^2$. Below is an east-west cross-section of the ice cap from Thule to the east coast.

2. The figure at the end shows the temperature of the ocean on a vertical section at latitude 60°N in the Atlantic Ocean. Explain the major features of the plot. In class, the colder temperatures were colored blue, the warmer temperatures red.

3. Grand Coulee dam generates electricity as falling water turns electric turbines (such a generator is like an electric motor running backwards). It produces about $10^{10}$ watts (10,000 megawatts). If the water is falling 150 m, calculate the flow rate (in m$^3$/sec) of the water. [Neglect energy loss due to friction.] How many average Americans does this supply with electricity?
4. Explain the cycle of a simple heat engine, with reference to heat input, pressure variation and work output. What meant by the ‘efficiency’ of this engine?

3. Essay question: write roughly 2 pages, single-spaced. Choose 1 of the following topics:

1. Scientists and policy makers are currently devising strategies for storing our waste carbon dioxide in the ocean (either by increasing the natural carbon pump or directly piping the carbon dioxide to the seafloor). Evaluate the wisdom of this plan by explaining the global carbon cycle. In other words, explain the flow of carbon from the atmosphere into the ocean. Be sure to include the roles of phytoplankton, bacteria, and nutrients. Also important are the consequences resulting from more carbon dissolved in the ocean as well as the capacity of the ocean to store carbon. Drawing a diagram might make your essay easier to understand.

2. Several authors we have read this term have expressed ideas about human energy… ‘somatic’ energy. What would these authors (particularly McNeill, Hawkens/Lovins, Lomborg, and even Richard Brown and Gretel Ehrlich) say about the relative importance of the physical energy output of humans, compared with their other effects on the environment? Describe the change through history of this effect.

3. You are a UW-Honors-educated scientist working for the BP (‘Beyond Petroleum’) oil company in the year 2015. Your next assignment is to travel to the coast of Greenland to assess new deposits rich in oil and natural gas which have just been discovered. Your suitcase and airplane ticket in hand, you turn to your supervisor and say “But, ……” Complete your statement, which is about 2 pages long.