Atmospheric Sciences 101

Homework #1 Solutions

!!! Show your work !!!
!!! Remember units !!!

General comments: The mean was about 23/30. If you scored 25/30 or above, you are probably doing fine. If you scored below 20/30, you might consider getting some extra help or starting the homework problems sooner in case you run into questions. This homework was very math-intensive, which will not be the case in most future assignments. Also note that homework is due at the beginning of CLASS, not in quiz sections, on the date indicated at the top. If you work as a group, make sure that all of your answers are in your OWN WORDS. Also, we can only give you partial credit if you show your work.

1. a) In a distant galaxy, a star slightly smaller than the sun emits radiant energy with maximum emission at a wavelength of 1.2 micrometers (1.2×10^{-6} m). Using $c=\lambda\nu$, what frequency does this wavelength correspond to? Express this in exponential notation.

The equation given above can be written in three equivalent forms:

$$c=\lambda\nu \qquad \lambda=c/\nu \qquad \nu=c/\lambda$$

where λ ("lambda") is the wavelength of the electromagnetic radiation (expressed in meters, or micrometers, or possibly some other unit of length) and ν ("nu") is the frequency of the radiation (expressed in Hertz (Hz), or 1/s, or cycles per second). In this problem, since you know c, the speed of light, and λ, the wavelength, you want to use the third form above:

$$\nu = c/\lambda = (3\times10^{8} \text{ m/s}) / (1.2\times10^{-6} \text{ m}) = 2.5\times10^{14} \text{ Hz}$$

Common mistakes were to write the formula upside down or to work out the exponents wrong. Remember: $10^{8} / 10^{-6} = 10^{14}$! Also, make sure that the units work out correctly--since we are asking for frequency, the units should be Hz = 1/s.

b) Using Wien's Law, calculate the temperature of the star in part (a) above. (Assume that the star behaves like a blackbody.) Convert your answer into degrees Fahrenheit.

Using the formulas from the lecture: T (in Kelvin) = 2897 / λ (in micrometers)
= 2897 / 1.2 = 2414 K
T (in Celsius) = 2414 - 273 = 2141 °C
T (in Fahrenheit) = (2141 x 1.8) + 32 = 3886 °F

Note that in Wien's law, the wavelength must be expressed in **micrometers** (not in meters) and the temperature is in Kelvin (then you can transform Kelvin temperature into Fahrenheit or Celsius). Also, you were welcome to use the formula from the book, but we warned you that the units were different than the formula we gave you in lecture.

2. a) Assume Mars has a surface temperature of 193 K. What is the wavelength of maximum emission by the surface of Mars? (Assume that Mars behaves like a blackbody.) Express your answer in both micrometers (microns) and meters.

Again, use Wien's Law, but solve for wavelength: λ (micrometers)= 2897 / T (Kelvin)

λ = 2897 / T = 2897 / 193 = 15 μm = 1.5×10^{-5} m

Please note:
1 meter = 1,000 millimeters, written **mm** or 1 mm = 10^{-3} m
1 meter = 1,000,000 micrometers, written **μm** or 1 μm = 10^{-6} m

b) Based on your answer to part (a), which gas do you think would be an important contributor to a "greenhouse effect" on Mars? Explain. (Assume that all of these gases are present in the Martian atmosphere in concentrations similar to those found on Earth.):

Water vapor: absorbs mainly at 2.7μm (and shorter wavelengths) and at 6.3 μm
Carbon dioxide: absorbs mainly at 15 μm and longer wavelengths
Ozone: absorbs mainly at 9.6 μm
Methane: absorbs mainly at 2.3 μm and 6.1 μm
Nitrous oxide: absorbs mainly at 4.7 μm and 7.5 μm

Since the surface of Mars emits infrared radiation with maximum wavelength of emission around 15 μm, carbon dioxide will be a good absorber of the radiation emitted by the planet. It will radiate some of this energy back to the surface and thus provide a greenhouse effect on Mars.

3) A large metal tank is full of completely frozen water (ice). Using a thermometer, you measure the temperature of the tank as precisely 0°C. The mass of the ice is exactly 1000 kg (kilograms). You turn on a heater underneath the tank, and the tank conducts heat from the heater to the ice inside of the tank, melting some of the ice.

a) What is the temperature of the liquid water in the tank?

The temperature of the water and the temperature of the ice will both remain at 0°C until all of the ice melts. This is always true for a phase change (likewise, a pot of boiling water will remain at 100°C until all of the water is turned into water vapor).

b) What is the temperature of the remaining ice?

0°C, as above.

c) How much energy is required to melt all of the ice in the tank? (Hint: the latent heat of melting/freezing is $3.34x10^5$ Joules per kilogram.)

You need $3.34x10^5$ Joules to melt one kilogram of ice. Then you need 1,000 times as much energy to melt 1,000 kilograms of ice, or $3.34x10^8$ Joules.

4) Now all of the ice in the tank in Problem 3 has been turned into liquid water. The temperature of the water is 0°C. Once again, you turn on the heater underneath the tank.

a) How much energy is required to raise the temperature of the water to 30°C? (Hint: the specific heat of liquid water is approximately 1 calorie per gram per degree Celsius, or $4.2x10^3$ Joules per kilogram per degree Kelvin.)

You need 1 calorie to raise the temperature of 1 gram of water by 1°C. Then you need 1,000 calories to raise the temperature of 1 kilogram of water by 1°C, and 1,000,000 calories to raise the temperature of 1,000 kilograms of water by 1°C. If you want to raise the temperature of 1,000 kg of water by 30°C, rather than 1°C, then you need 30 times as much energy, or 30,000,000 = $3x10^7$ calories.
You can do the same reasoning with the specific heat in Joules:

Q = (1,000 kg) x ($4.18x10^{-3}$ J / kg / K) x (30 K) = $1.25x10^8$ J

Note that the change in temperature is 30K. Some of you transformed 30°C into 303K. 30°C is the <u>increase</u> in temperature from 0°C to 30°C. There are 30°C between 0°C and 30°C; similarly, if we work out the temperature <u>change</u> in degrees Kelvin, there are 30K between 273K and 303K!!!

b) Which has more heat: the water in the tank (at 30°C), or 50 kg of water at 99°C? Why?

Heat is a measure of the total internal kinetic energy. In 1,000 kg of water, there are many more molecules than in 50 kg of water, and consequently more <u>total</u> internal kinetic energy, thus more heat. Some of you calculated the energy required to raise the temperature of 50 kg of water up to 99°C, and compared it to the energy required to raise the temperature of 1,000 kg of water to 30°C. Although this is not wrong by itself, it is not the correct answer to the question. Even at 0°C, before you start heating, the tank already has a lot more internal kinetic energy than the 50 kg of water.

5. a) Using the data in Figure 3.9 in the textbook, determine the average temperature in Richmond and in San Francisco during January, April, and July. Convert all your answers into degrees Celsius and degrees Kelvin.

Your numbers might be slightly different than ours:

January:	San Francisco:	54°F; (54 - 32) x 1.8 = 12°C; 12 + 273 = 285 K
	Richmond	39°F; (39 - 32) x 1.8 = 4°C; 4 + 273 = 277 K
April:	S.F.:	59°F; (59-32) x 1.8 = 15°C; 15 + 273 = 288 K
	Rich.:	61°F; (61-32) x 1.8 = 16°C; 16 + 273 = 289 K
July:	S.F.:	61°F; (61-32) x 1.8 = 16°C; 16 + 273 = 289 K
	Rich.:	81°F; (31-32) x 1.8 = 27°C; 27 + 273 = 300 K

Remember significant figures! You can probably only read this graph to the nearest degree.

b) Using the following table, calculate the total precipitation received in each city (in inches) during a typical year. Convert your answer into meters (Hint: one inch equals approximately 2.54 centimeters, or $2.54x10^{-2}$ meters).

Month	*Richmond*	*San Francisco*
January	*5.7*	*8.4*
February	*6.1*	*9.1*
March	*6.6*	*9.3*
April	*6.9*	*8.7*
May	*7.1*	*6.2*
June	*8.0*	*3.5*
July	*6.9*	*1.4*
September	*6.6*	*1.7*
October	*5.4*	*4.4*
November	*5.3*	*7.1*
December	*5.4*	*8.2*

(note: precipitation is in INCHES)

Totals: 70.0 inches 68.0 inches

This is the amount of precipitation received in each city during a typical year. We did not ask you to compute the average monthly precipitation in each city, but you were not penalized if you did this instead.

To convert inches into centimeters, multiply by 2.54 cm per inch. This gives you 172.72 cm of precipitation in San Francisco and 177.80 cm in Richmond. Since there are 100 centimeters in one meter, this corresponds to about 1.78 meters in Richmond and 1.73 meters in San Francisco. Don't include too many significant figures in this computation.

c) If a San Francisco native asked you to describe the climate of Richmond relative to that of San Francisco, how would you respond? When is the "rainy season" at each location? Where is the seasonal temperature range greatest? Why do you think this is?

How do you think the daily range of temperature in San Francisco compares with the daily range of temperature in Richmond? Explain.

Richmond has nearly the same yearly precipitation and average temperature as Richmond, but there are marked seasonal differences. The rainy season in San Francisco is during the winter and early spring, while Richmond has relatively constant precipitation year-round (with a slight maximum in the summer months). The seasonal temperature range, or the summer temperature minus the winter temperature, is larger in Richmond than in San Francisco (about 22°F versus 5°F). In addition, the temperature peaks in Richmond earlier in the summer than in San Francisco. San Francisco has a smaller seasonal temperature range due to its proximity to the ocean, as the high specific heat of water moderates temperature changes there. Richmond is farther inland, and the relatively low specific heat of soil means that its temperature will fluctuate more. This argument also holds true for the daily temperature range, so I would expect Richmond to have a large diurnal temperature range also. Other factors also contribute to the seasonal differences between the two cities, such as soil moisture during the summer and cloud cover differences, but these effects are smaller than the specific heat argument and are directly related to the ocean nearby.

6. a) For each example below, state which energy transfer mechanism(s) is operating and briefly explain your choice (there may be more than one correct answer for each):

Note that there was more than one correct answer for most of these. I included a few possible answers for each example.

- you place a pot of water on an electric stove

CONDUCTION of heat from the burner to the pot and from the pot to the liquid water. CONVECTION also occurs in the liquid water inside the pot. The burner, pot, and water are also all RADIATING heat to the surrounding area...

- you get a sunburn

Solar RADIATION (mainly UV light) strikes your skin and provides the energy for the chemical reaction in your epidermis that we call sunburn.

- the handle of your fireplace poker heats up when you stir the fire

The handle heats up because of CONDUCTION of heat through the (solid) poker.

- you listen to the radio

Radio waves are one form of electromagnetic RADIATION. Radio waves are received by your radio, not by your ears (if this were true you could hear radio stations without the aid of a walkman). The radio then converts this radiation into an electrical signal, which requires electrical CONDUCTION through the electronic components of the radio. The radio speaker emits sound waves that you hear, but sound waves are NOT a form of electromagnetic radiation. We did not deduct points if you called sound waves "conduction" by air molecules because this is approximately true. Note that sound waves require air to travel (there is no sound in space), but radio waves do not require any medium to travel--they can travel through empty space and we can use them for astronomical observations for this reason.

- snow melts off the hood of your car after you start the engine

Heat is CONDUCTED from your hood to the snow. This does not require the movement of any molecules (both the hood and the snow are solids). Some people also noted that the reason the hood is warm is because heat from the engine RADIATES and CONVECTS from the engine to the hood above. The liquid water from the melted snow is probably not convecting heat because it must remain at 0°C while it is in contact with the snow.

- vultures circle carrion on a hot summer day without moving their wings

Vultures and other large birds often use thermals to rise without flapping their wings. Thermals are an example of CONVECTION in the atmosphere, but there are other processes operating here also: RADIATION from the sun strikes the ground, and the ground warms up. The warm ground CONDUCTS heat to the very bottom layer of the atmosphere (which is only a few molecules thick), and because this air is now warmer and less dense than its surroundings (we will discuss this in class soon), it rises via CONVECTION and the vultures can remain aloft because of this upward flow of air.

b) For each example below, state the form(s) of energy present and briefly explain your choice (again, there may be more than one correct answer for each):

- you eat breakfast in the morning

Breakfast is chemical POTENTIAL energy. The act of eating requires movement, which implies external KINETIC energy.

- you see *a lump of silly putty on the ground*

When you SEE something, it is the result of reflection of shortwave (visible) RADIATION. Moving your eyeballs again implies KINETIC energy. The putty on the ground is higher than, say, your basement, so it also has gravitational POTENTIAL energy. And the putty is above absolute zero so it is also RADIATING infrared energy.

- you pick up the silly putty and lift it up to eye level

The act of lifting implies external KINETIC energy. Once the putty is at eye level, it possesses gravitational POTENTIAL energy relative to its previous position on the ground.

- you drop the silly putty (which weighs 0.5 kg), and right before it hits the ground it is travelling at 2 meters per second. Calculate the external kinetic energy of the silly putty.

external K.E. $= (1 / 2)\ m\ v^2$

$= (1 / 2) \times (0.5\ kg) \times (2\ m/s)^2$

$= (1 / 2) \times (0.5\ kg) \times 4\ m^2/s^2$

$= 1\ kg\ m^2 / s^2 = 1$ Joule (J)

- when the silly putty hits the ground, it stops and deforms. Where do you think the energy went? (Hint: if you throw the putty against a wall repeatedly, it gets warm).

The deformation of the silly putty stretches some of the intermolecular bonds and creates friction as the different parts of the putty slide past each other. As you can demonstrate by rubbing your hands together rapidly, friction produces heat, which is INTERNAL KINETIC energy. Thus the external kinetic energy of the falling putty is transformed into internal kinetic energy. Subsequently, this heat will exit the putty via CONDUCTION to the ground and also RADIATION into the surrounding air.