

Practice Exam 4A  
 Physics 100, Spring 2007  
 Wednesday, May 16<sup>th</sup> 2007

Useful Equations and Numbers

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Acceleration due to gravity...  
 on Earth =  $10 \text{ m/s}^2$   
 on Mars =  $3.7 \text{ m/s}^2$   
 on the Moon =  $1.6 \text{ m/s}^2$

$$(wave \ speed) = wavelength \times frequency$$

$$frequency = \frac{1}{period}$$

$$f_{max} = T(Kelvin) \times 10^{11} \text{ Hz/Kelvin}$$

$$T(Kelvin) = T(Celsius) + 273$$

$$speed \ of \ light = 300,000,000 \text{ m/s} = 3 \times 10^8 \text{ m/s}$$

$$E_{photon} = h f$$

$$h = 6.62 \times 10^{-34} \text{ J/Hz}$$

$$Angle \ of \ Incidence = Angle \ of \ Reflection$$

$1 \text{ Hz} = 1 \frac{cycle}{sec} = \frac{1}{sec}$	$1 \text{ km} = 1,000 \text{ m} = 0.6 \text{ miles}$
$1 \text{ MHz} = 1,000,000 \text{ Hz} = 10^6 \text{ Hz}$	$1 \text{ hour} = 3,600 \text{ seconds}$
$1 \text{ minute} = 60 \text{ seconds}$	$1 \text{ g} = 10 \text{ m/s}^2$
$1 \text{ m/s} = 3.6 \text{ km/hour}$	$1 \text{ Newton} = 1 \frac{kg \cdot m}{s^2}$
$1 \text{ m} = 3.2 \text{ feet}$	$1 \text{ Joule} = 10,000,000 \text{ ergs}$
$20 \text{ m/s} = 45 \text{ mph}$	$1 \text{ mile/minute} = 60 \text{ mph}$

**DO NOT OPEN EXAM UNTIL INSTRUCTED TO DO SO!  
 TURN OFF YOUR CELL PHONE!**

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## Answer Key for Exam A

### Section 1. True/False (1 pt. each)

*Warm up!*

- True Blue light is more strongly scattered in the atmosphere, which causes the sky to appear blue and sunsets to appear red.
- False The energy of a photon is proportional to its wavelength.
- True The hotter something is, the higher the frequency of light that it gives off.
- False Electromagnetic waves tend bend towards regions where they travel more quickly.
- True The fundamental difference between visible light and ultraviolet radiation is the difference in wavelengths/frequencies.
- True The wavelength of 400 nm light traveling in water is shorter than 400 nm light traveling in air.
- False An ultraviolet photon has less energy than an infrared photon.
- False Blue light has a smaller frequency than red light.
- False When an electron in an atom decays and gives off a photon, it can do so through *spontaneous emission* or *electrophosphorescent emission*.
- True If an atom can emit 540 nm light, then it can absorb 540 nm light, too.
- False If a beam of light is coherent, then all the photons that make it up have the same frequency, phase, and direction of travel, but not the same wavelength.
- True A object that is fluorescing is absorbing light of one frequency and emitting light at a lower frequency.

Section 2. **Multiple Choice (2 pts. each)**

Choose the single best answer unless instructed to do otherwise.

Hint: they're not all (C)!

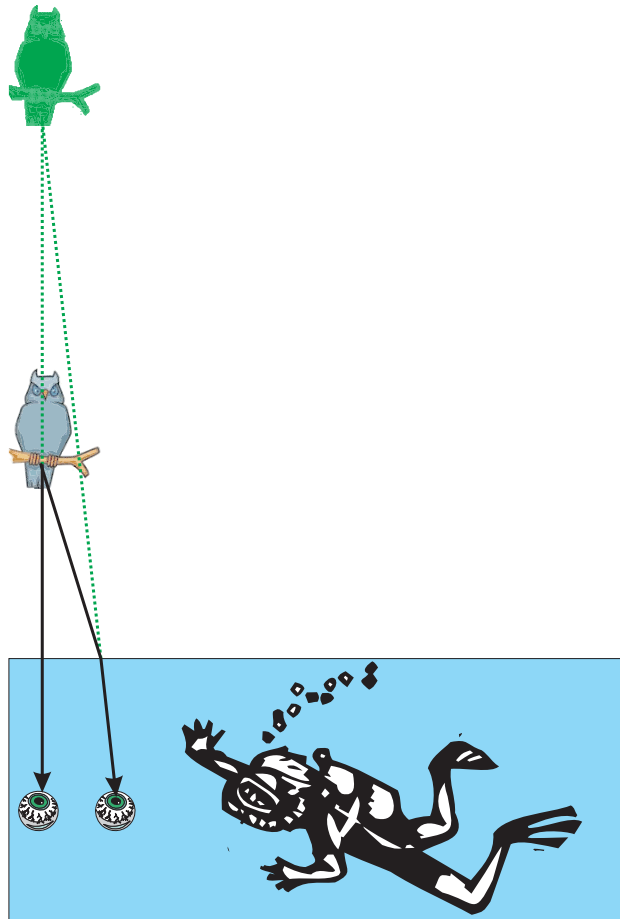
1. How is it that astronomers can tell if stars many light-years away are moving away or towards us?
  - (a) This is a trick question: they can't!
  - (b) They can look at how Fraunhofer lines are Doppler shifted.
  - (c) They can measure the peak emission wavelength of the star and determine its temperature.
  - (d) They can use laser-rangers from Earth to determine how far away the stars are.
  
2. Which of the following are examples of electromagnetic waves (circle all that apply)?
  - (a) x-rays
  - (b) radio waves
  - (c) visible light
  - (d) microwaves
  - (e) ultrasonic waves
  
3. Which of the following light source(s) is best described by the following statement?

Light is generated by heating up a filament to a very high temperature, usually by passing electricity through it. The frequency of the emitted light is proportional to the temperature of the filament.

  - (a) Incandescent light bulb
  - (b) Fluorescent light bulb
  - (c) LASER
  - (d) Neon Sign
  - (e) Phosphorescent light bulb
  
4. Which of the following is/are true?
  - (a) The speed of light in warm air is slower than in cold air because the atoms in cold air don't take as much of its energy.
  - (b) The speed of light in warm air is faster than in cold air because the gas molecules are moving faster and therefore Doppler shift the light to higher velocities than cold air would.
  - (c) The speed of light in warm air is faster than in cold air because the density of warm air is lower so that there are fewer atoms per unit volume to slow the light down.
  - (d) The speed of light in cold air is faster than in cold air because the density of cold air is lower so that there are fewer atoms per unit volume to slow the light down.
  - (e) The speed of light in warm air and cold air is the same because it's *sound waves* that travel in air– light doesn't need a medium..

Section 3. Short Answer Questions (10 pts. each)

5. You are swimming underwater and look up to see a bird sitting in a tree.  
(A) Would the bird appear to be closer or farther away from you than it actually is?  
(B) In the figure below, draw at least two light rays that support your answer to part (A).



**Figure 1:** You're swimming underwater and look up to see a bird. It will appear to be farther away than it actually is. See Problem 5

**Answer:**

- (A) It will appear to be farther away from you than it actually is– the reverse of looking at a fish in the water from the air.  
(B) See the diagram. I chose to draw the rays to a set of eyeballs just under the bird (I didn't need to use the diver!). This makes it easy to see because a ray coming straight into the water goes straight into the water (it's already bent towards the slow medium as much as possible).

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6. Imagine what would happen if the Earth's atmosphere scattered green light much more strongly than red and blue light and that it scattered red light just as strongly as blue light.
- (A) What color would the noon sky be?
  - (B) What color would sunsets be?
  - (C) What color would the Sun look like?
  - (D) During a lunar eclipse, what color would the moon appear to be?
  - (E) What color would dessert 'water' mirages be?

**Answer:**

- (A) The noon sky would appear to be *green*, because as you look at the sky, you'll see the light that is most strongly scattered.
- (B) The light that makes it through the atmosphere for sunset will have none (or most) of the green light absent, and will be dominated by the mixture of blue and red light. Your eyes would perceive this as magenta (I'd accept purple, too).
- (C) The Sun would appear to be less green, as the green light from the Sun would get scattered away (just as in real life the blues get scattered more than the reds, turning the green sun yellow). This would mean that the Sun would look a little magenta.
- (D) During a lunar eclipse, the Earth's atmosphere acts like a lens to focus sunlight onto the Moon, which otherwise receives no light. Only the light that could make it through the atmosphere could illuminate the Moon, so in this case, the moon would look magenta.
- (E) Mirages in the desert that look like water are due to the sky's light being refracted. Since the sky is green, the water mirages would appear to be green— so they'd be less of water mirages and more like grass mirages.

**7. Quick Calculations:**

(A) If you were  $300,000,000,000,000\text{ m}$  ( $3 \times 10^{14}\text{ m}$ ) away from the Sun when it suddenly ‘turned off,’ how long would it take for you to know?

(B) How long, in years, will aliens on a planet  $500\text{ light years}$  away have to wait to see this season’s finale of *America’s Next Top Model*? Assume that the alien’s planet is not moving with respect to the Earth and that the TV signal is being carried by radio waves.

(C) Imagine it’s a warm day. What is the peak electromagnetic emission frequency of your skin, assuming that it is  $27^\circ\text{C}$ ?

(D) Using your answer from part (C), what peak wavelength would your skin radiate at?

(E) Compared to the energy of a  $150\text{ nm}$  photon, how much energy does a  $600\text{ nm}$  photon have?

**Answer:**

(A) Use the equation  $distance = rate \times time$ . The rate would be the speed of light. Solving for the time:

$$time = \frac{distance}{rate} = \frac{300,000,000,000,000\text{ m}}{300,000,000\text{ m/s}} = 1,000,000\text{ s} = 11.6\text{ days}$$

(B) Since the planet is  $500\text{ light years}$  away and radio signals travel at the speed of light, the aliens will have to wait  $500\text{ years}$ . Remember: a light year is the distance light travels in one year.

(C) Use the equation for blackbody emission:

$$f_{max} = (10^{11}\text{ Hz/Kelvin}) \times T(\text{Kelvin}) = (10^{11}\text{ Hz/Kelvin}) \times 300\text{ Kelvin}$$

$$f_{max} = 3 \times 10^{13}\text{ Hz}$$

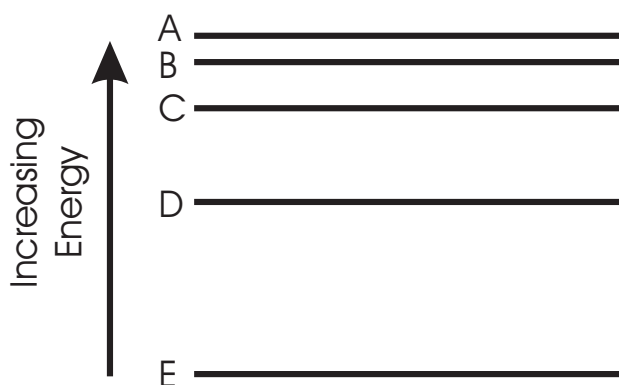
(D) Use everyone’s favorite wave equation:  $v = \lambda f$ :

$$\lambda_{max} = \frac{c}{f_{max}} = \frac{3 \times 10^8\text{ m/s}}{3 \times 10^{13}\text{ Hz}} = 1 \times 10^{-5}\text{ m} = 10\text{ }\mu\text{m}$$

Where a  $\mu\text{m}$  is a micron:  $1\text{ micron} = 10^{-6}\text{ m}$ . This happens to be well into the infra-red. Night vision goggles that can see people in the dark are looking for this wavelength of light!

(E) The energy of a photon is proportional to it’s frequency. A  $150\text{ nm}$  photon has 4 times the frequency of a  $600\text{ nm}$  photon (wave equation!), so therefore it has 4 times the energy.

8. An energy level diagram for an imaginary atom is drawn below.
- (A) How many different wavelengths of light can the atom emit?
  - (B) How many different wavelengths of light can the atom absorb?
  - (C) Which energy level is the ground state?
  - (D) If this atom were to fluoresce, describe how a photon might be emitted, taking into account all of the required steps starting with the excitation of the electron in the atom to the emission of the final photon. Note that there is no unique solution to this question.



**Figure 2:** The energy levels for the fictitious atom in Problem 8

**Answer:**

(A) Every possible transition in the atom corresponds to a spectral line. In other words, for every different pair of energy levels, a different wavelength of light can be made. Here are the different possible transitions:

$A \rightarrow E$	$A \rightarrow D$	$A \rightarrow C$	$A \rightarrow B$
$B \rightarrow E$	$B \rightarrow D$	$B \rightarrow C$	
$C \rightarrow E$	$C \rightarrow D$		
$D \rightarrow E$			

From the table, it is easy to see that there are 10 different transitions, so there are 10 spectral lines (wavelengths of light).

(B) It can emit the same number of wavelengths that it can absorb. Therefore, it can absorb 10 different wavelengths.

(C) The energy level corresponding to the lowest energy is the ground state. In this case, E is the ground state.

(D) Fluorescence is caused by an atom absorbing a photon and its energy and then re-emitting the energy in one or more photons with lower energy than the first (meaning that they have a lower frequency and corresponding longer wavelength). Two example solutions follow:

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Example Solution 1	Example Solution 2
Atom absorbs photon: The electron makes the transition $E \rightarrow A$	Atom absorbs photon: The electron makes the transition $E \rightarrow A$
Atom emits a lower-energy photons: The electron makes transition $A \rightarrow C$	Atom loses some energy in a collision with another atom: The electron makes transition $A \rightarrow D$ , but <i>does not emit a photon</i>
Atom emits another lower-energy photon: The electron makes transition $C \rightarrow D$	Atom emits a lower-energy photon, returning to the ground state: The electron makes transition $D \rightarrow E$
The atom emits yet another lower-energy photon, returning to the ground state: The electron make transition $D \rightarrow E$	The atom is already in the ground state

Again, to emphasize, there are many possible solutions to this problem. A valid solution would have to mention how the atom gets excited by absorbing a photon and how it then in turn gives off one or more photons of lower energy than the one it absorbed.

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9. A large ship is coming towards shore and is communicating with a land-based command tower using radio waves. An interesting thing happens: as the ship approaches the shore, the communications signal gets stronger, then weaker, then stronger again. Explain what is happening using words and a diagram. *Hint: radio waves can bounce off of water.*

**Answer:** The water acts like a mirror, creating an image of the radio antenna. Just as in your homework problem, this will lead to a two-source interference pattern with dead zones and strong zones. The only difference is that the sources (the radio antenna and its image) are moving toward the land-based command tower so that the dead zones and strong zones sweep past it, giving rise to the signal fading in and out. The same effect was demonstrated with two tuning forks: when you walked past them (or leaned to the side in your seat), you would hear the sound get stronger and weaker.