Science-1A Lecture: Week-6, Monday, February 15, 2021

Quiz-3 is next week, so today I will go over the Example Questions for Quiz 3 and their solutions. These are at *https://yosemitefoothills.com/Science-1A/QuizAndTestPractice/SampleQuestions-Quiz-3.pdf* and *https://yosemitefoothills.com/Science-1A/QuizAndTestPractice/SampleQuestions-Quiz-3-Solutions.pdf* .

See the boxed note at the start of the Week-2 Monday lecture at *https://yosemitefoothills.com/Science-1A/OnlineLectureAndLabNotes/Week-02-Lecture-Monday-January-18-2021.pdf* for an explanation of the Equation Sheet and its use.

The following discussion is long, but I needed to try an anticipate the points of confusion that I easily clarify during a spoken lecture. It may be a pain to read, but it was also a pain to write. **Study this note carefully because you must do the work without any reference to this note while taking Quiz 3.** Only a clean Equation sheet is to be used when taking the Quizzes and Tests.

The calculation answer style shown in the solutions sheet is the style that should be followed when writing calculation solutions. I will be fussy about writing the starting equation, and if required, alterations to it. Also, the setup should have proper mathematical form and values should be written with their units using parentheses if appropriate. The final answer should have 3 or 4 significant figures unless more are requested, and of course, answers should have the correct units.

This is the last quiz with lots of calculations questions, so study it well knowing that the others will be easier. You will, however, see them again in the Physics Midterm and in the Final Exam, so don't forget them.

Question 1: (2 points) The swinging ball demonstration called Newton's Cradle is shown in the following videos:

Newton's Remarkable Cradle
https://www.youtube.com/watch?v=JNYS1ZhTJRA

GIANT Newton's Cradle with Bowling Balls
https://www.youtube.com/watch?v=7DO01QQSls0

Newton's Cradle demonstrates that the number of balls swinging out after the collision always matches the number of balls coming in. Conservation of momentum might allow two balls to go out at half the speed of a single ball coming in, but Nature insists that only one ball comes out with the same speed as the single incoming ball. **What other law** is needed to explain this? The video explains the answer which is "**The law of conservation of energy".**

Question 2: (2 points) In an elastic collision where no energy is lost to heat, **what two laws of physics** are applicable?

Conservation of Momentum and Conservation of Energy

Conservation of energy alone or conservation of momentum alone are not sufficient. Both must be applied to predict what Nature does when things collide.

> Note: **Even when they do not collide elastically, energy is conserved.** Some of the energy just becomes an unpredictable amount of heat. In elastic collisions no heat is generated, and we can use conservation of kinetic energy to complete the equations needed to predict the subsequent motion.

Question 3: (2 points) **How much energy (work)** is required to raise a **weight** of 20 N by a height of 3 m against gravity at the surface of the earth?

Work is force multiplied by distance moved in the direction of the force. When raising a weight, the force is its weight and the distance is how high it was raised. (If you see a question like this that gives the mass instead of the weight, you need to convert the mass to weight by multiplying by the acceleration of gravity $g = 9.80\,\mathrm{m/s^2}$ which is at the middle of page 1 of your Equation Sheet.)

$$\boldsymbol{W = F \cdot h = (20\,\mathrm{N}) \cdot (3\,\mathrm{m}) = 60\,\mathrm{N \cdot m} = 60\,\mathrm{J}}$$

Question 4: (3 points) **How much energy (work)** is required to raise a **mass** of 5 kg by a height of 2 m against gravity at the surface of the earth?

Here, the mass needs to be converted to force (weight) using $F=mg$ where g at the surface of the Earth is 9.80 m/s^2 as given on the middle of the first page of your Equation Sheet. Any of the 3 answers given is correct, but the first answer using $kg \cdot m^2/s^2$ lets the units be more easily checked against the setup equation.

$$\boldsymbol{W = F \cdot h = m g h = (5\,\text{kg}) \cdot (9.8\,\text{m}/\text{s}^2) \cdot (2\,\text{m}) = 98\,\frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = 98\,\text{N} \cdot \text{m} = 98\,\text{J}}$$

Question 5: (2 points) If a person does 10 MJ of work in 500 seconds, **how much power** is required?

An equation for calculating power is in middle of the Chapter 3 section on page 2 of your Equation Sheet: $\text{power} = \frac{\text{work}}{\text{time}}$. We are given the work and time in this problem, so we simply divide them. Using joules and seconds will automatically give us watt, the unit of power abbreviated by a capital W. The problem used MJ which needed to be converted to 10^6 J to produce watts. Look for unit conversion factors and replace them with the appropriate power of 10. Also, always convert time units like days and hours to seconds.

Don't be confused by an italic *W* used for work in the following equation. Italic *W* is work, non-italic W is the unit for power, the watt.

$$\boldsymbol{P = \frac{W}{t} = \frac{10 \times 10^6\,\text{J}}{500\,\text{s}} = 20 \times 10^3\,\frac{\text{J}}{\text{s}} = 20 \times 10^3\,\text{W} = 20\,\text{kW}}$$

Question 6: (3 points) If a 50 kg person hikes up 3000 m in 5 hours, **how much power** is required using the unrealistic assumption that the person's muscles are 100% efficient?

This problem is like the previous one except that you are given the mass and you must calculate the work using the formula $W=mgh$ that is in the middle of the Chapter 3 section on page 2 of your Equation Sheet. This equation comes about from the definition of work being force multiplied by distance in the direction of force with the force being the person's weight, *mg*. (On page 1 of the Equation sheet, a lower-case italic *w* is used for weight. There are too many w's in mechanics!) Also, don't forget to convert any time units to seconds!

$$\boldsymbol{P = \frac{W}{t} = \frac{mgh}{t} = \frac{(50\,\text{kg}) \cdot (9.8\,\text{m}/\text{s}^2) \cdot (3000\,\text{m})}{(5\,\text{h}) \cdot \left(\frac{3600\,\text{s}}{1\,\text{h}}\right)} = 81.7\,\frac{\text{kg} \cdot \text{m}^2}{\text{s}^3} = 81.7\,\frac{\text{J}}{\text{s}} = 81.7\,\text{W}}$$

Question 7: (2 points) **How many calories** are in 100 J?

This question requires you to use the conversion factor found at the end of the Chapter 4 section on page 2 of your Equation Sheet. You use $\frac{1\,\text{cal}}{4.186\,\text{J}}$ or $\frac{4.186\,\text{J}}{1\,\text{cal}}$ depending on which unit needs to be cancelled. In this case J needs to be cancelled so the first version is used.

$$\boldsymbol{(100\,\text{J}) \cdot \left(\frac{1\,\text{cal}}{4.186\,\text{J}}\right) = 23.89\,\text{cal}}$$

Question 8: (2 points) **How many food calories** are in 100 J?

As noted at the end of the Chapter 4 section on page 2 of your Equation Sheet, 1 food calorie is 1000 cal. That way it won't look so scary when we eat a cookie labeled 100 cal which is really 100 food cal = 100000 cal! Often food cal are distinguished from cal by using a capital C, Cal, so 1 Cal = 1000 cal and your cookie is 100 Cal. This problem requires two conversions, food calorie to calorie and then calorie to joules. In this class, I always spell out "food calorie" rather than use "Cal" or "Calorie".

$$\boldsymbol{(100\,\text{J}) \cdot \left(\frac{1\,\text{cal}}{4.186\,\text{J}}\right) \cdot \left(\frac{1\ \text{food calorie}}{1000\,\text{cal}}\right) = 0.02389\ \text{food calorie}}$$

Question 9: (4 points) A person burns about 1500 food calories **per day**. **How much power** is the person generating from that food?

Here we need to convert food calories to joules to get the work in joules, but since the question asks for power, we need to divide the work by the time in seconds. The time is given in hours, so the hours need to be converted to seconds. Many students work hard on the top part of this answer, but then forget to divide by the time. Don't forget to divide by time converted to seconds when calculating power!

$$\frac{(1500\ \text{food calories})\cdot\left(\frac{1000\,\text{cal}}{1\ \text{food calorie}}\right)\cdot\left(\frac{4.186\,\text{J}}{1\,\text{cal}}\right)}{(1\,\text{day})\cdot\left(86400\,\frac{\text{s}}{\text{day}}\right)}=72.7\,\frac{\text{J}}{\text{s}}=72.7\,\text{W}$$

Question 10: (2 points) A 2000 kg pickup truck is moving at 100 km/h. **How much kinetic energy** does it have?

The definition for kinetic energy *KE* is $KE=\frac{1}{2}mv^2$ on the 6th line of the Chapter 3 section on page 2 of the Equation Sheet. This problem requires the conversion of km to m and h to s, but often students will forget to square the velocity. Make sure your setup follows the *KE* equation including the square! The first answer has units that follow directly from the setup, but are equivalent to N·m and simply J. Forgetting the square will cause you to get units of $\text{kg}\cdot\text{m/s}$ rather than the correct $\text{kg}\cdot\text{m}^2/\text{s}^2$. The units are your friends. Let them help you remember the square.

$$KE=\frac{1}{2}mv^2=\frac{1}{2}(2000\,\text{kg})\cdot\left[\left(100\,\frac{\text{km}}{\text{h}}\right)\cdot\left(\frac{1000\ \text{m}}{1\,\text{km}}\right)\cdot\left(\frac{1\,\text{h}}{3600\,\text{s}}\right)\right]^2=7.72\times10^5\,\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}=7.72\times10^5\,\text{N}\cdot\text{m}=7.72\times10^5\,\text{J}$$

Question 11: (2 points) If a 3 kg rock is dropped a height of 5 m, **how fast** is it moving when it hits the ground?

The first part of the answer below shows you how to derive the required formula $v=\sqrt{2gh}$ by equating the gravitational energy at the start with the kinetic energy at the bottom. In fact, however, you are given the required formula at the last line of the Chapter 3 section of page 2 of the Equation Sheet. Again, if your setup is wrong, you will not get m/s as the units for the answer. As always, check your units when you get an answer. Sometimes students ask me if I forgot to give the mass in this problem, but in fact, the answer does not depend on the rock's mass.

$$mgh=\frac{1}{2}mv^2 \quad \text{so} \quad v=\sqrt{2gh}=\sqrt{2\cdot(9.8\,\text{m/s}^2)\cdot(5\,\text{m})}=9.90\,\text{m/s}$$

(Note: This result is independent of the mass.)

Question 12: (2 points) A temperature reading is -30 ºC, what is the **temperature in kelvin**?

The first line of the Chapter 4 section on page 2 of your Equation Sheet has the necessary formulas to convert temperature between K and ºC. The 273 value is a **difference** in temperature which can have either K or ºC units since both of those scales have the same size of degrees. Saying "the temperature **rose** 25 K" is the same as saying "the temperature **rose** 25 ºC", but saying the temperature "**is** 25 K" is saying the temperature is 25 degree units above absolute zero temperature (−248 ºC). Saying the temperature "**is** 25 ºC" is saying that is is near room temperature (298 K).

$$T_K=T_C+273\,\text{K}=-30\,^{\circ}\text{C}+273\,\text{K}=243\,\text{K}$$

Question 13: (2 points) Liquid helium boils at 4.2 K, what is that **temperature on the Celsius scale**?

See the note for #12. This is just doing the reverse of question #12 so a minus sign is involved.

$$T_K=T_C+273\,\text{K} \quad \text{so} \quad T_C=T_K-273\,\text{K}=4.2\,\text{K}-273.0\,\text{K}=-268.8\,^{\circ}\text{C}$$

Question 14: (6 points) Give the semi-joking phrases that describe the three laws of thermodynamics **and** briefly explain what they mean:

1st: You can't win. – No machine can be devised to create new energy.
2nd: You can't even break even. – Perpetual motion machines cannot be built.
0th or 3rd: You must play the game – You are part of the universe and are governed by its laws.

These should be pretty easy to remember. Perpetual motion machines are machines that keep going on forever and never slow down. They do not exist. Even the Earth going around the sun is losing some energy. Undisturbed atoms are very close to perpetual, but even they will eventually be hit by something that changes them. **Don't forget to write both parts of each law.**

The next 5 questions are related to the "warming cold ice to hot steam" graph at
https://yosemitefoothills.com/Science-1A/Handouts/Week-04/IceToSteam.pdf .
These questions demonstrate the use of each of the 5 equations at the middle part of the Chapter 4 section on page 2 of the Equation Sheet. Three of the questions deal with changing the temperature of ice, water, and steam, and the other two deal with changing ice to water and changing water to steam. The ones dealing with a changing temperature have units of $\frac{\text{cal}}{\text{g}\cdot{}^{\text{o}}\text{C}}$ whereas the ones dealing with changing ice to water at 0 ºC or water to steam at 100 ºC, have units of just cal/g . **Be careful to note whether the mass is given in kg or g.** If it is given in kg, you need to convert it to g so that it can cancel the per g part of the units of these equations. You do not need to convert your answers to kcal. Just giving the result of your setup equation, cal, is safer.

Question 15: (2 points) **How many calories** are needed to melt 2 kg of ice at 0 ºC?

$$q = m\,L_f = (2000\,\text{g})\cdot\left(80\,\frac{\text{cal}}{\text{g}}\right) = 160000\,\text{cal} = 160\,\text{kcal}$$

Question 16: (2 points) **How many calories** are needed to turn 4 kg of water to steam at 100 ºC?

$$q = m\,L_v = (4000\,\text{g})\cdot\left(540\,\frac{\text{cal}}{\text{g}}\right) = 2160000\,\text{cal} = 2160\,\text{kcal}$$

Question 17: (2 points) **How many calories** are needed to heat 40 kg of water from 20 ºC to 50 ºC?

$$q = m\,c_{water}\,\Delta T = (40000\,\text{g})\cdot\left(1.00\,\frac{\text{cal}}{\text{g}\cdot{}^{\text{o}}\text{C}}\right)\cdot\left(50\,^{\text{o}}\text{C} - 20\,^{\text{o}}\text{C}\right) = 1200000\,\text{cal} = 1200\,\text{kcal}$$

Question 18: (2 points) **How many calories** are needed to warm 300 g of ice from -50 ºC to -10 ºC?

$$q = m\,c_{ice}\,\Delta T = (300\,\text{g})\cdot\left(0.50\,\frac{\text{cal}}{\text{g}\cdot{}^{\text{o}}\text{C}}\right)\cdot\left[-10\,^{\text{o}}\text{C} - \left(-50\,^{\text{o}}\text{C}\right)\right] = 6000\,\text{cal} = 6.00\,\text{kcal}$$

Question 19: (2 points) **How many calories** are needed to heat 40 kg of steam from 100 ºC to 150 ºC?

$$q = m\,c_{steam}\,\Delta T = (40000\,\text{g})\cdot\left(0.48\,\frac{\text{cal}}{\text{g}\cdot{}^{\text{o}}\text{C}}\right)\cdot\left(150\,^{\text{o}}\text{C} - 100\,^{\text{o}}\text{C}\right) = 9.60\times10^5\,\text{cal} = 960000\,\text{cal} = 960\,\text{kcal}$$

The next two questions are very similar. Heat engines convert between heat flow and work. A refrigerator uses work to take heat out of its interior and deposits heat in its back panel or fins in its base. The work done by the motor/compressor in the refrigerator adds to the heat removed so that the exhaust heat is greater.

Similarly, a steam engine uses hot steam to push a piston that does mechanical work and exhausts cooler steam. The difference in input and exhaust heat is the work performed by the piston.

So in both cases, the work required (W_{in}) or the work performed (W_{out}) is the difference in heat converted from calorie energy units to joule energy units. Don't forget the conversion factor $4.186\,\text{J}/\text{cal}$. **Your answer must be in joules.**

Question 20: (2 points) An engine performs work in a cyclic process that takes in 1500 cal of heat at a higher temperature and exhausts 500 cal of heat to a lower temperature. **How much work** did it do?

$$\mathbf{W_{out} = Q_H - Q_L = 1500\,cal - 500\,cal = 1000\,cal = \left(4.186\,\frac{J}{cal}\right)\cdot\left(1000\,cal\right) = 4186\,J}$$

Question 21: (2 points) A refrigerator compressor doing work on a gas in a cyclic process that takes in 500 cal of heat at a lower temperature and exhausts 1500 cal of heat to a higher temperature. **How much work** must its compressor do?

$$\mathbf{W_{in} = Q_H - Q_L = 1500\,cal - 500\,cal = 1000\,cal = \left(4.186\,\frac{J}{cal}\right)\cdot\left(1000\,cal\right) = 4186\,J}$$

There are two types of equations that deal with waves. They are on the first line of the Chapter 5 section on page 2 of your Equation Sheet. One connects frequency and period, and the other connects frequency, wave velocity, and wavelength. Look at the problem you are confronted with and see if it asks about wavelength or velocity. If not, you simply use the formula $f = \frac{1}{T}$ or its inverse $T = \frac{1}{f}$. Only one version is given on the Equation Sheet, your are expected to use algebra to figure out the other version.

If the problem asks about or uses wavelength, then you need to use the equation connecting wave velocity with wavelength and frequency. For sound, you will be given the velocity in the problem statement, but for electromagnetic waves like light and radio, you will need to use the speed of light found on the 3rd line of the Chapter 5 section of page 2 of your equation sheet. The letter *c* is used for the speed of light which is exactly 299792458 m/s, but you should simply use the approximation 3.00×10^{8} m/s. Both are given on the equation sheet.

Question 22: (2 points) A **sound** wave (speed = 340 m/s) has a frequency of 5 kHz, **what is its wavelength**? The letter *v* is used for the speed of sound and the Equation Sheet gives the starting point for this question $v = \lambda f$. Be careful to look for unit prefixes on the wavelength or frequency. **The example below does not have any, but the question you meet on a quiz or test might use kHz, MHz, GHz, etc, or mm, μm, nm, etc.!** You will need to convert to Hz or m when using this equation because the velocity is in m/s.

$$\mathbf{v = \lambda f \quad so \quad \lambda = \frac{v}{f} = \frac{340\,m/s}{5\times 10^{3}\,Hz} = \frac{340\,m/s}{5000\,s^{-1}} = 0.068\,m}$$

Question 23: (2 points) A wave has a **period** of 0.0002 s, **what is its frequency**?

$$\mathbf{T = \frac{1}{f} \quad so \quad f = \frac{1}{T} = \frac{1}{0.0002\,s} = \frac{1}{2\times 10^{-4}\,s} = 0.5\times 10^{4}\,Hz = 5\times 10^{3}\,Hz = 5000\,Hz}$$

Here, there is no velocity or wavelength so we simply use $T = 1/f$ as our starting point. Pay close attention to units. If the frequency is given in Hz, then the period is in s, but if the frequency is given in kHz, MHz, GHz, etc, the frequency prefix will need to be replaced by 10^3, 10^6, 10^9, etc. as appropriate. You must know your unit prefixes!

Question 24: (2 points) Sound travels faster at (**higher**, ~~lower~~) temperatures. Circle the correct word.

Since $\mathbf{v_{T_p} = 331\,m/s + \left(0.600\,\frac{m}{s\cdot{}^{o}C}\right)\cdot T_p}$ **, it is faster at higher temperatures.**

You will **not** need to use the equation given here. It is on your Equation Sheet, but is left over from when I was following the text more closely. **You do need to know, however, that sound travels faster when the temperature is hotter.** That is because sound is carried by moving molecules that move faster at higher temperatures.

Question 25: (2 points) If an instrument has a beat frequency of 4 Hz when compared with a 440 Hz tuning fork, its frequency is either __**444**__ Hz or __**436**__ Hz. It should be adjusted until the beat frequency is __**0**___Hz.

You can hear what this question is talking about in the audio clip at *https://yosemitefoothills.com/Science-1A/Handouts/Week-05/BeatFrequency.wav* where there are tones at two frequencies, one fixed at 440 Hz and the other one gradually changing from 435 Hz to 445 Hz. Halfway through the clip, the frequencies are equal and the condition of "zero beat" is attained. Musicians use the zero beat condition between their instruments to tune their frequencies to a tuning fork or other reference frequency. Notice that the beat frequency is 5 Hz whether the changing note is 5 Hz below or 5 Hz above the reference note. For Question 25, the beat frequency is 4 Hz and the reference frequency is 440 Hz so the answers are 444 Hz and 436 Hz. The adjustment is made until the beat frequency becomes 0 Hz.

Question 26: (2 points) The **intensity** of a sound is measured to be 10 W/m^2. **How much power** is received by a microphone with an **area** of 1 cm^2?

The definition of sound intensity is shown at the 5th line of the Chapter 5 section of page 2 of the Equation Sheet as sound divided by an area that it impinges upon. In this question that area is the 1 cm^2 area of a microphone. The question gives the sound intensity *I* and asks for the sound power *P*, so the formula on the Equation Sheet is rearranged to become $P=I \cdot A$. A unit conversion is required, however, because the intensity was given in W/m^2 and the area was given in cm^2. Keep an eye open for the need for such conversions since m^2 and cm^2 do not cancel without a factor of 100^2. The answer below includes a conversion to mW, but leaving the answer in W is better since that is what results from the setup equation.

$$I=\frac{P}{A} \quad \text{so} \quad P=I\cdot A=\left(10\,\frac{\mathrm{W}}{\mathrm{m}^2}\right)\cdot\left(1\,\mathrm{cm}^2\right)\cdot\left(\frac{1\,\mathrm{m}}{100\,\mathrm{cm}}\right)^2=0.001\,\mathrm{W}=10^{-3}\,\mathrm{W}=1\,\mathrm{mW}$$

Question 27: (2 points) A person twice as far from an explosion as another person receives (~~the same~~, ~~one-half~~, **one-forth**, ~~one-eight~~) the sound energy. Circle the correct answer.

The energy of an explosion weakens as the explosion spreads out in both the vertical and horizontal directions. As a result a fixed area like that of an eardrum receives an energy reduced as the square of the distance. Twice as far away receives 1/4 the energy per unit area, 3 times as far away receives 1/9, 4 times a far away receives 1/16, etc. So in this case the answer is 1/4.

Question 28: (2 points) A child pumping a swing and a musician playing a stringed or wind instrument are all using the __**resonance**__ effect to generate large changes at specific frequencies from small stimuli.

Resonance is when a driving force, such as a child's pumping, synchronizes with a natural frequency of a device in a manner that keeps putting energy into the device. At each pump, the child adds energy to the swing until the swing's motion has become so great that energy loss to air resistance and the suspension mechanism matches that provided by the child.