Physics 101
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Solutions to Problems - Chapter 3 (Earth Equilibrium)

1. *Imagine that you are 10 m away from a light source. As you move away from the light source, it gets dimmer. When you are 20 m away from the light source, how much less intense will be the light reaching your eyes?*
D) $1/(2)^2 = 1/4$ *times as intense*
The distance from the light source has changed from 10 m to 20 m, i.e., it has doubled. The intensity of light changes inversely with the square of the distance away from the light source. Thus, if the distance increases (here, it is doubled) the intensity decreases (that is the inverse part). The amount by which it decreases is $1/2^2 = 1/4$, i.e., the intensity is 1/4 as great which was choice D.

2. *Imagine that you are 12 m away from a light source. You change your position so that you now see the light source to be 9 times less intense. Where are you located now? B) 36 m away*
The intensity decreases by a factor $1/9 = 1/(3)^2$. This means that the distance increased by a factor of 3. The original distance from the light source was 12 m, so the new distance must be 12 x 3 = 36 m—choice B.

3. *Imagine that you are 12 m away from a light source. You change your position so that you now see the light source to be 9 times more intense. Where are you located now? C) 4 m away*
The intensity increases by a factor of 9. This means the distance decreases by a factor of $\sqrt{9} = 3$. Since the original distance was 12 m, the new distance must be 12/3 = 4 m. Compare this to the previous problem which goes in the opposite direction (i.e., in that problem the intensity decreases by a factor of 3, so the distance must increase 3-fold.)

4. *Consider two light bulbs — bulb 1 is nine times more powerful than bulb 2 (for example, if bulb 1 is 90 watts then bulb 2 would be 10 watts). Which statement is not true?*
C) Bulb 1 and bulb 2 can never appear to be equally intense — bulb 1 will always appear brighter to an observer.
In choice A, this is what the wattage of a bulb means. A 100 watt bulbs consumes (or gives off) electrical energy at the rate of 100 joules every second. Choice A is true.
In choice B, if you were to move three times further away from bulb 1 (increase distance by a factor of 3), the intensity would decrease by a factor of $1/(3)^2 = 1/9$. This is exactly the reduction in intensity necessary to make bulb 1 appear to have the same intensity as bulb 2. Choice B is true.
Choice C is false, as was proven in the discussion of choice B. Choice B gives the condition under which bulbs 1 and 2 will appear equally intense.

5. *The temperature of a blackbody is halved. By what factor does the intensity change? A) It becomes 1/16 as great.*
The intensity is a measure of the number of joules of energy radiated every second which is the power radiated. The Stefan-Boltzmann Law relates theintensity to the fourth power of the temperature, i.e., $P \alpha (T)^4$. If the temperature is made half as great the power radiated is one-half to the fourth power as great. Thus, $\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}\ \frac{1}{2} = \frac{1}{16}$

6. *The temperature of a blackbody changes from 4,000˚K to 10,000˚K. By what factor does the intensity increase? Ans. D)*
What is of interest is the factor by which the temperature increases, not the actual increase. In going from 4,000˚K to 10,000˚K, the actual increase in temperature is 6,000˚K. However, what is of interest to us is the ratio of the final temperature to the original temperature. Thus, the temperature has increased by a factor of 10,000/4,000 = 2.5. According to the Stefan-Boltzmann Law, an increase in the temperature by a factor of 2.5 increases the intensity by $(2.5)^4$ which is $2.5\ 2.5\ 2.5\ 2.5 = 39.1$
Note that multiplying 2.5 times itself four times to get $(2.5)^4$, is the same thing as (2.5·2.5) · (2.5·2.5). But, since (2.5·2.5) = 6.25, this is the same thing as 6.25·6.25 which is $(6.25)^2$. Thus, to find the fourth power of any number, you can first square the number and then square the result.

7. *You are looking at two stars that are the same distance away. One star appears to be 16 times brighter than the other. What can you say about the relative temperatures of the two stars? Ans. A)*
There are two things that we have talked about in class that determine how bright a light source appears to be:
1) the distance away. The Inverse Square Law tells us that the intensity of a light source decreases inversely as the square of the distance—if you double the distance (if nothing else is considered) the intensity is 1/4 as bright.
2) the temperature. According to the Stefan-Boltzmann Law, the power (which determines the intensity) varies as the fourth power of the temperature.
If we are comparing two light sources that are at different temperatures and are also different distances away, then to find the relative brightness, one would have to take into account both the Stefan-Boltzmann Law and the Inverse Square Law, which is much more complicated. (I will not ask you to do this.) In this problem you are told that the distance to the two stars is the same, so the Inverse Square Law does not enter into the solution of the problem. The temperature of the brighter star is 2 times greater than the

other star. If one star is 16 times brighter than the other, it means that T^4 for this star is 16 times greater than T^4 for the other star. This means that the temperature of the cooler star is the fourth root of 16. Just as we saw above in problem #6, we can find the fourth power of a number by first squaring, then squaring again, we can work back the other way in this problem by first finding the square root of 16 and then taking the square root of that result. The square root of 16 is 4. Taking the square root again is the square root of 4 which is 2. Thus, the fourth root of 16 is 2.

8. *The temperature of a blackbody increases so that the intensity is increased by a factor of 16. By what factor was the temperature increased? Ans. A)*
This question asks the same thing as in question #7, only in different words and, of course, the answer is the same. In problem #7, you had two different light sources and you were asked to determine the temperature of the cooler one compared to the temperature of the hotter (brighter) one. In this problem, there is only one light source, but you are asked to compare its temperature when it is cooler to its temperature when it is heated to 16 times greater brightness. In both problems, the brightness increases by a factor of 16 when the temperature is changed by a factor of the fourth root of 16 (written as $\sqrt[4]{16}$) which equals 2.

9. *The temperature of a blackbody increases so that the intensity is increased by a factor of 81. By what factor was the temperature increased?*
Ans. B The reasoning here is identical to that discussed above for questions #7 and 8 with an increase in the power by a factor of 81 rather than 16. The temperature change that produces an 81-fold increase in the power is found by finding the fourth root of 81. First, find the square root of 81, which is 9. Now, determine the square root again, i.e., the square root of 9 is 3.

10. *A blackbody at 3000˚K has the peak wavelength on the brightness curve (the wavelength at which the maximum energy is radiated) at 1000 nm. What will be the peak wavelength at 1000˚K?*
Ans. A. The temperature is reduced by a factor of 3. According to the Wien Displacement Law the temperature and peak wavelength have a simple inverse relationship. Thus, reducing the temperature by a factor of 3 increases the peak wavelength by the same factor, i.e., it will change from 1000 nm to 3000 nm.

11. *Our sun has a temperature of about 6000˚K and appears to be yellow in color. If you look into the heavens and see a star that has a bluish tint to it, what can you conclude about the temperature of the star?*
Ans. The bluish tint to the star implies that there is more energy output in the blue-violet wavelengths of the visible spectrum than does our sun. Bluish color implies that shorter wavelengths are being radiated than the yellow peak from our sun. The Wien Displacement Law, which defines an inverse relationship between peak wavelength and temperature, then implies that the temperature of this bluish looking star is higher than 6000˚K.

12. A blackbody at 6000˚K has the peak wavelength on the brightness curve (the wavelength at which the maximum energy is radiated) at 550 nm. If you look at the same object later and note that the peak wavelength has changed to 1650 nm, which of the following is a correct conclusion?
Ans. D Ans. This can be understood from the Wien Displacement Law. The peak wavelength has changed from 550 nm to 1650 nm which is 3 times greater. This implies that the temperature is *decreased* by a factor of 3, i.e., from 6000˚K to 2000˚K.

13. Assuming that the wattage of a light bulb represents the the true amount of light energy radiated per second (it doesn't!) how much higher is the temperature of a 100 W bulb compared to a 25 W bulb?
Ans. E. The power of the 100 W bulb is 100/25 = 4 times greater than the power radiated by the 25 W bulb (i.e., it is 4 times brighter). From the Stefan-Boltzmann Law, this implies that the temperature must be higher by the fourth root of 4. (See the discussion of the answers to problems #7 and 8 for a detailed explanation. The only difference with this problem is that, in those problems, we were considering a brightness that was 16 times greater rather than 4 times greater.) To find the fourth root of 4, we first determine the square root of 4 which is 2. Then, we take the square root again. Our answer here is the square root of 2 which is 1.41, which was NOT one of the choices given.

14. In your Lecture Notes (page GW-3.5) there are several blackbody radiation curves (graphs of brightness vs. wavelength) for different temperatures. According to these curves, if you had an electric stove with the burners at a temperature of 1500˚C, it would not glow. However, when the temperature got to 2000˚K, the burner would glow "red-hot". Explain this.
Ans. Refer to the figures on page GW-3.3 in the notes. Note that, at 1500˚C, essentially the entire radiation curve occurs at wavelengths longer than 700 nm which is where the red end of the visible light spectrum is. Thus, at 1500˚C, the stove does not "glow" visible light, but it is radiating lots of infrared radiation (with wavelengths longer than 700 nm). At 2000˚C on the other hand, the radiation curves includes some radiation (although weak—there is still some) with visible light wavelengths. This is shown by the shaded area in the figure. Although most of the radiation coming from the stove at this temperature is also infrared (as it is at 1500˚C) there is now some red-orange visible light being radiated as well. It is this radiation that we can see and gives the appearance that the stove burner is glowing "red-hot".