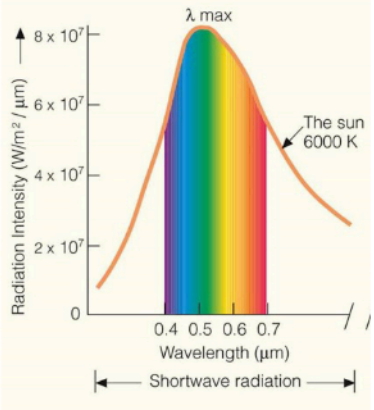
Hints to Practice Questions

1. The radiation profile of sun is given by the following graph:



In a high security location, there are cameras and sensor of all kind which are sensitive to the entire solar spectra. A group of thieves are planning to enter the premise at night. One of them has a background in physics, who advises the others that wearing a mask would not be too helpful. What strategy should they use to escape the law enforcing agencies?

Hints: A black mask can absorb visible radiation and one can evade CCTV cameras. However, thermal cameras can capture the radiation profile and can be used to reconstruct the face of the person. A solution is to cover the face with metallic masks with significant gap between the face and the metal. The metal will emit thermal radiation but the phase information will be lost and it will be impossible to reconstruct the image of the person.

2. A black charcoal and a white stone are inserted in a hot oven and it soon, they start glowing and acquire the colour of the oven? Why? When they are cooled, they acquire different temperature. Explain the physics.

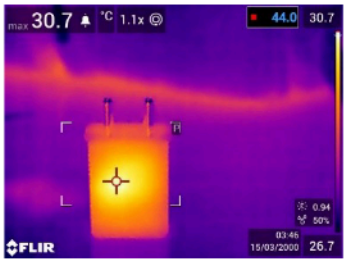
Hints: At high temperatures, the electrons go to higher states and emit light as they move to lower states. The electrons in a charcoal and oven are in very high energy state, so they emit light which is similar to the colour of oven. At room temperature, the electrons are in lower energy state and they emit light depending on the existing energy state of the electrons. [An example from acoustics would illustrate it clearly: When two people are talking normally, you can clearly distinguish their voices, but when they are shouting at a loud pitch in a crowded environment, where everyone is shouting, it would be difficult to identify their distinct voices.]

3. When objects are heated, why do their temperatures change?

Hint: Heat transfer excites the energy of oscillations of atoms. This appears as a change in temperature. Temperature, in fact is a measure of how the atoms are vibrating.

4. According to Stefan Boltzmann law, energy radiated per unit time, per unit area is defined by just one quantity, temperature. If that is the case, why is the thermal image of the object

shown below is showing a gradation of colour, although, the entire structure is that the same temperature?



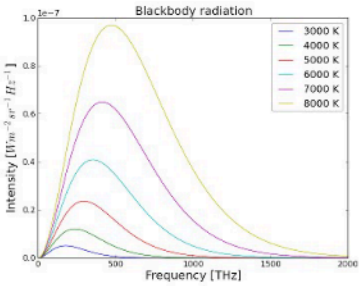
Hint: The entire structure is at the same temperature, but depending on the composition of the material, thickness, spatial alignment etc. the spectrum emitted is different. If we capture the entire energy spectrum, we will find that it is just a function of temperature, however, in the current image, we are only seeing the thermal profile i.e. only infrared radiation is being captured.

5. The radiated energy density per unit frequency is given by,

   ¿ $\frac{8\pi \nu^2 k T}{c^3}$, where ν is frequency is k is Boltzmann constant, T is temperature and c is speed of light what is ultraviolet catastrophe and in what way is it related to the above equation? What does kT indicate in the above equation?

Hint: KT indicates the total energy. An atom at a temperature T will have this much of energy. If there are N atoms, the total energy is NKT.

6. The graph for black body radiation is given below



You have to design a camera, which can take pictures in the dark, in what way, the above graph can assist you?

Hint: In the dark, there is radiation in the visible spectrum. Radiation from shorter wavelengths are not that intense. So, use of cameras which capture UV radiation is not too useful. The best option we have is to use thermal radiation i.e. infrared radiation. Night vision cameras extensively use this principe.

7. Does black body radiation have something to do with black colour?

Hint: Black colour absorbs visible light. Black body radiation absorbs all spectrum and radiates them back. So, in terms of its ability to absorb, there is some similarity with black objects, which absorb radiation. But in strict scientific terms, there is relationship between them.

8. A black object absorbs visible light. What happens to the radiation?

Hint: It is absorbed and gets radiated as em radiation in other frequency bands. In many cases, it is radiated as infrared radiation.

9. What was the main contribution of Planck. Explain the significance of the following equation, which was derived by Planck

$$Average\,energy\,,\,E=\frac{h\nu}{e^{\frac{h\nu}{kT}}-1}=kT$$

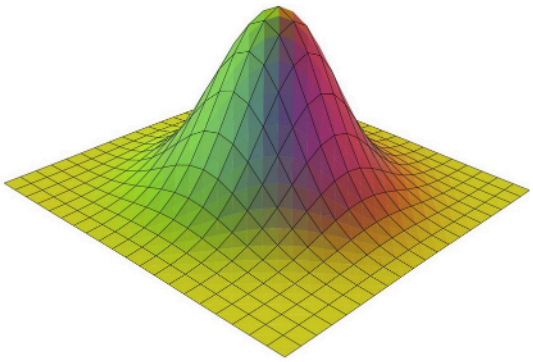
Hint: The equation derived by Rayleigh and Jeans could not satisfy the graph for black body radiation, which did not work at high frequencies. Planck focused on the term KT in the expression and considered that there are simple harmonic oscillators present in a body, which are generating radiation. He assumed that the energy of these oscillators are quantized units of $h\nu$. He used Maxwell-Boltzmann distribution of gases and replaced the energy term with the quantized energy and worked out the mathematics to get the above term, which satisfied the radiation associated with black body.

10. The equation below is called Maxwell-Boltzmann distribution,

    $N_i = Nexp(-E_i/kT)$:
    What is its significance, in what way, is it related to normal distribution or Gaussian distribution.

Hint: It states that higher energy molecules are less in number in a given sample. It is related to Gaussian distribution. If we replace the energy term with kinetic energy of atoms, we get a Gaussian distribution of velocities.

11. Human settlement can also follow normal distribution and population density in a typical city follows the following distribution in space (the vertical axis indicates density and the remaining two axes indicate geographic spread)



    Assuming that the dynamics of people's movement follows Boltzmann distribution, which would be the best place from the center to set up a business. Comment.

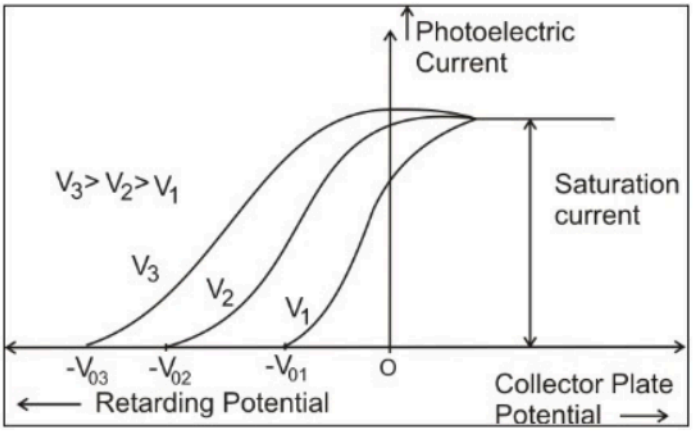
Hint: It indicates that density in a city centre would be high. It also implies that speed at which people move, could also be higher. Business has multidimensional angle and needs. It implies that businesses which match the fast pace of needs of people and high density, should be located at the city centre. However, businesses, where the pace is not too high, e.g. a theme park, can be located outside the city.

12. How is radiation generated. What was Planck's contribution in our understanding of radiation?

From the perspective of classical electromagnetism, radiation is generated when electrons accelerate. Quantum mechanical perspective argues that radiation is an outcome of change of state of an elelctron, i.e. an electron makes a transition from high energy to low energy state.

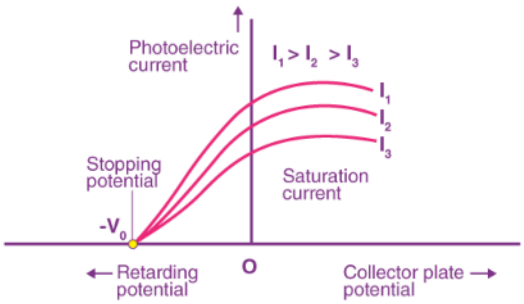
Questions on Photoelectric Effect

1. What does the following graph indicate? Why does the current level saturate (does not increase) after some time?



Hint: Electrons generated move to the collector. Every electron has a finite potential and it repels other electrons. After some time, there is high concentration of electrons and the collector plate voltage increases to an extent that it does not allow any more flow of electrons.

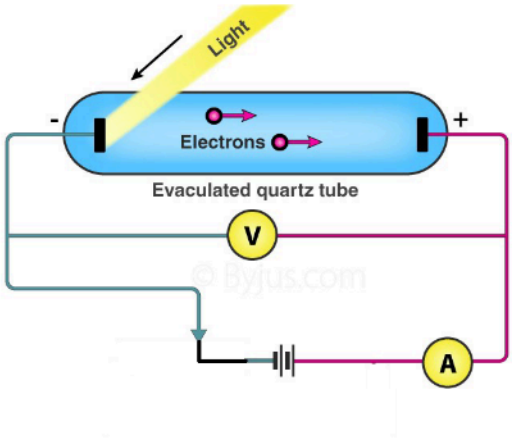
2.How do you calculate the frequency of light from the following graph?



Hint: According to photoelectric equation, KE= $h\nu - h\nu'$, where ν' is the threshold frequency, KE is kinetic energy of electrons.

If the current is I, the total charge over a time t is $q=It$. Thus, we can write, $qV_0 = h\nu - h\nu'$. This expression can be used to find the threshold frequency.

3. What is the role of voltage source in the experimental set up of photoelectric effect?



Hint: The voltage source can change the overall value of current. The value at which the current is zero can be used to determine the threshold frequency.

4. What was the contribution of Philip Lenard in photoelectric effect?

Hint: Philip Lenard did a more methodical study of photoelectric effect and was the first to investigate the frequency dependence of electron energy.

5. What was the contribution of Einstein in Photoelectric effect? In what was it related to Planck's work?

   Hint: Einstein used the work by Planck to explain that light can be considered to be packets of energy of light quanta.

6. What is the biggest weakness of photoelectric effect which led to a long time in its broader acceptance?

   Hint:It cannot explain momentum conservation.

7. A photon generates an electron in photoelectric effect, but if photons are particles, what happens to these particles after electrons are generated, do they still remain around in the system?

Hint: Photons vanish as their energy is absorbed by the electrons.