

Radio Astronomy

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Radiative Transfer - Tutorial 01

Hello everyone, I am Harsha Avinash Tanti and I am your TA for this radio astronomy course. I am currently a research scholar pursuing my PhD under the supervision of Professor Raghuram Datta who is also the course instructor of this course. And welcome to your second week tutorial course. In this lecture what we will do, we will study some sample questions on radiative transfer which was not covered in the earlier lectures. So let us begin with reviewing what is radiative transfer. So if I define there are four kinds of radiative transfer, the first one being emission where there is a media which is due to some reason it is emitting some radiation and due to this emission the system is cooling down.

Now the second one is absorption where a medium is absorbing all the electromagnetic radiation coming from the surrounding. The third one is thermodynamic equilibrium means the amount of emission and absorption is same. So energy contained in the system is same. And the fourth one is LTE, local thermodynamic equilibrium wherein in a macroscopic scale you will have non-equilibrium whereas in local scale in smaller region you will have thermodynamic equilibrium.

So let us see our first example. So the first example is about when the temperature of a medium increases the emission spectrum of the medium will what will shift to a higher energy or shorter wavelength radiation, shift to a lower energy or longer wavelength radiation remain unchanged as temperature does not affect emission. So both shift higher and lower energy radiation.

1. When the temperature of a medium increases, the emission spectrum of the medium will:
 - (a) Shift to higher energy (shorter wavelength) radiation
 - (b) Shift to lower energy (longer wavelength) radiation
 - (c) Remain unchanged, as temperature does not affect emission
 - (d) Show both shifts to higher and lower energy radiation

So I will give you a 10 second time try to answer it and after that we will proceed to what is the actual answer to this question. So the correct answer is A, the energy they shift to higher energy shorter wavelength radiation.

See if a system's temperature increases due to and you have studied Planck's blackbody radiation so due to Planck's law what will happen since the temperature increased and it has a direct correlation with the intensity so intensity will increase and also that means the wavelength will also decrease because intensity has inverse relation with your wavelength.

Let us move forward to another sample question, that is a radiative equilibrium in a planetary atmosphere occurs when the temperature remains constant throughout the atmosphere, energy absorbed by the atmosphere equals to energy emitted back into the space, conduction dominates over the radiation in heat transfer the atmosphere is completely transparent to radiation. So your 10 second starts now.

2. Radiative equilibrium in a planetary atmosphere occurs when:
 - (a) The temperature remains constant throughout the atmosphere
 - (b) Energy absorbed by the atmosphere equals energy emitted back into space
 - (c) Conduction dominates over radiation in heat transfer
 - (d) The atmosphere is completely transparent to radiation

So the correct answer is B, the energy absorbed by the atmosphere is equals energy emitted back into the space. So the equilibrium in a planetary atmosphere will only happen if there is thermodynamic equilibrium maintained.

This is T. So if there is a medium here and emission both are same then and then only the rate of emission and absorption is equal and the temperature is maintained same. Now moving to the other sample question. In a scenario where absorption significantly exceeds emission in a medium the temperature of the medium will what? Increase increase or remain constant or there will be a periodic fluctuation?

3. In a scenario where absorption significantly exceeds emission in a medium, the temperature of the medium will:
- (a) Decrease due to energy loss from absorption
 - (b) Increase due to energy gain from absorption
 - (c) Remain constant, as absorption and emission balance each other
 - (d) Experience periodic fluctuations in temperature

So the correct answer to this question is option B, the energy will increase because if absorption increases what will happen? The medium will heat the temperature will rise.

If the temperature will rise how? Because it is absorbing all the energies from the photon and this is also known as what? This is also known as radiative heating, a phenomena called radiative heating where the absorption is significantly high. If you for an example you go out in a sunny day so what you will feel from the you will feel more heat on your skin that is because you are absorbing photons emitted by the sun. And also your environment is also getting heated up because of other phenomena but there is also one reason that your body is absorbing the IR radiations. So moving to another sample question. This is a NAT type question.

4. A certain gas cloud in space absorbs radiation at a rate of 5×10^{-9} Watts/m³. If the cloud has a volume of 10^6 m³, calculate the total energy absorbed by the cloud in 1 hour.

So we will go through it means like it is quoting that there is a gas cloud which absorbs radiation at the rate of 5 into 10 to the power minus 9 watts per meter cube. If it is given the clouds volume is 10 to the power 6 meter cube and it is saying calculate the total energy absorbed in 1 hour. So here if you do not clearly remember the way to answer is the trick is to see the units. So watts per meter cube are so you know what is that power is equals to energy over time. So energy is equals to what? Power into time.

This is the hint to solve it. So the correct answer to this question is 18 watts. How? See absorption rate is given per meter cube and you have the volume. So you just multiply by the volume you will get the power in watts. So power in watts will be what? 5 into 10 to the power minus 3 watts and you have given 1 hour of time and energy is calculated in what? Joules which is in seconds.

You have to multiply this 3600 with 5. So you will get 18 watts. Let us move on to another exciting problem. This problem says that there is a material with thickness 5 centimeter. There is a thickness of 5 centimeter and it has absorption coefficient of what? It absorbs 60 percent of the incident radiation.

A material sample has a thickness of 5 cm and absorbs 60% of incident radiation. If the intensity of incident radiation is 1000 W/m^2 , calculate the linear absorption coefficient (μ) of the material.

Now intensity of the radiation is given. You have to find what is the linear absorption coefficient. So the trick is here you have given the percentage of radiation absorbed and the thickness and based on this you have to calculate the absorption coefficient. So the answer to this question will be 8000 per meter. So by using the formula the intensity absorbed will be what? Incident intensity into 1 minus the transmittance.

Transmittance is what? 60 percent only. The incident intensity is what? Given in meter square. So 1 minus this we will get what? We will get this quantity and absorbed intensity is nothing but your mu into you can say thickness you can. So mu into thickness you can or in other terms actually the formula will be divided by mu and the mu will come here. So this what you get is coming around to be 8000.

Now let us move on to the final question of the day.

So we have to consider a medium here with given a scattering coefficient and absorption coefficient and there is also mentioned that there is an intensity which is incident on the medium. It has an absorption coefficient and scattering coefficient. Now there is a wave coming some of will scatter and some of will be absorbed. And the thickness given here is 20 centimeter. Now what you have to calculate is the transmitted through the medium means the radiation which is entering and transmitting through it.

- Consider a medium with a linear scattering coefficient (σ_s) of 0.1 cm^{-1} and a linear absorption coefficient (σ_a) of 0.05 cm^{-1} . If the incident radiation intensity (I_0) is 100 W/m^2 and the medium has a thickness of 20 cm, calculate the intensity of radiation (I) transmitted through the medium.

So the answer to this question will be 36.79 watt per meter square. So using the transmission coefficient formula for we will have which is this we will have what tau is

0.05 into 20 centimeter 0.05 per centimeter is what your optical means tau is your optical depth where s is the scattering coefficient sigma s the scattering coefficient into this and scattering and this is the your absorption coefficient. Now you calculate the tau on based on the optical depth then calculate the optical depth which is tau equal to 1 and from that you can calculate the intensity. So let us again revisit the values here it is mentioned that absorption coefficient is 0.5. So that is why the tau value here is 0.05 into 20 centimeter. So this is how the tau came to be and tau see centimeter to the power minus 1 and centimeter so dimensionless quantity tau is coming out to be what 1.

To calculate the intensity of transmitted radiation, we can use the equation of radiative transfer:

$$I = I_0 \times e^{-\tau}$$

$$I = I_0 e^{-\tau}$$

where I = Intensity of transmitted radiation, I_0 = Incident radiation intensity, τ = Optical depth of the medium, $\tau = \sigma_a \times d$ for absorption and $\tau = \sigma_s \times d$ for scattering, d = Thickness of the medium.

Substitute the given values:

$$\tau = 0.05 \text{ cm}^{-1} \times 20 \text{ cm}$$

Calculate the optical depth:

$$\tau = 1$$

Now, use the equation of radiative transfer to find the transmitted intensity:

$$I = 100 \text{ W/m}^2 \times e^{-1}$$

$$I \approx 36.79 \text{ W/m}^2$$

So, the intensity of radiation transmitted through the medium is approximately 36.79 W/m^2 .

So that is how you do it. So thank you.