NATIONAL TECHNICAL UNIVERSITY OF ATHENS

SCHOOL OF ELECTRICAL & COMPUTER ENGINEERING

DIVISION OF ELECTROMAGNETIC APPLICATIONS, ELECTRO-OPTICS & ELECTRONIC MATERIALS

Prof. Elias N. Glytsis, Τηλ.: 210-7722479 - *e-mail:* eglytsis@central.ntua.gr - *www:* http://users.ntua.gr/eglytsis/

OPTICAL ENGINEERING

Problem Set No. 1

Due Date: March 12, 2024

(The problems that should be submitted have nonzero weighting factors)

Problem 0 (deBroglie wavelength): (0%)

Find the kinetic energy (in Joule and in eV), the momentum, and the deBroglie wavelength of an electron when: (a) its velocity is $1\times10^5 m/s$ and (b) its velocity is $0.99c$ where $c = 2.99792458\times10^8 m/s$ is the velocity of light in freespace (vacuum). Useful date: electron rest mass $m_0 = 9.10938291\times10^{-31} kg$, Planck's constant, $h = 6.62606957\times10^{-34}\, J\, s$, and $1\text{eV} = 1.602176565\times10^{-19} J$.

Problem 1 (Blackbody Radiation): (0%)

The radiation emitted by our Sun can be approximated by the radiation emitted by a blackbody with maximum energy density per unit wavelength at $\lambda_m = 501.4$nm. (a) Find the electromagnetic power per unit area (in W/m^2) that arrives on Earth from the Sun. (b) If it is assumed that Earth is in constant temperature (in thermodynamic equilibrium) and emits radiation as a blackbody what would be Earth's equivalent temperature in degrees Kelvin? (c) For a better approximation in the previous question, it can be accounted the reflected Sun radiation by the Earth. The average power reflection coefficient of the Sun radiation by the Earth (known as *Albedo*) is about 30%. If the Earth's ***albedo*** is taken into account what would be its equivalent temperature in degrees Kelvin?

Sun's mean radius is R_s= 696000km, Earth's mean radius is R_e= 6371km, and the mean distance between Sun and Earth is D = 149600000km.

Problem 2 (Coherence): (0%)

(a) A white light source has almost uniform energy spectrum in the range between 400nm and 700nm. (b) A laser light source has almost uniform energy spectrum in the range 693.4nm $\pm$ 10^{-5}nm. For light sources (a) and (b) estimate the temporal coherency times as well as the temporal coherency lengths.

Problem 3 (Laser Modes): (0%)

Assume that the center wavelength of a He-Ne laser is exactly 632.8nm. What is the corresponding frequency of the laser light? If the distance between the planar mirrors of the laser cavity is 50cm, find the integer q for the laser mode that is the nearest to the center frequency. If the spectral Full-Width-at-Half-Maximum (FWHM) of the gain curve of the laser is 1GHz, find the number of longitudinal modes of the cavity that fit under the gain curve of the laser.

Problem 4 (Photometry-Brightness Comparison): (0%)

In an optical laboratory the output of two lasers are viewed (with the eye) under identical conditions (for example the laser beams could be allowed to strike a diffusing screen). The first laser is a 10 mW Helium-Cadmium laser (λ_0 = 441.6nm) and the second laser is a 1.5 mW Helium-Neon laser (λ_0 = 632.8 nm). All conditions are identical except for the wavelengths and radiant powers. Which laser would appear brighter ? Show your calculations.

Problem 5 (Lighted Panel Switch): (0%)

An illuminated panel switch has a square, flat area of 5 mm by 5 mm in size. By filtering of the light of an incandescent bulb, it emits red light of a wavelength of 630 nm. It assumed to emit light into a Lambertian distribution. The radiant optical power emitted is 10^{-6} watts. Calculate (a) the luminous power, (b) the luminous intensity normal to the surface of the switch, and the (c) the luminance.

Problem 6 (Photometric Quantities): (0%)

An argon ion laser emits 2.8 watts of power at a wavelength of λ_0 =514.5 nm. The beam diameter at the output of the laser is 1.4 mm. The beam diverges and is incident upon a screen that is 10 m away. The axis of the beam is normal to the screen. (a) Calculate the luminous power at the screen. (b) Calculate the illuminance on the screen in footcandles within the illuminated region. Assume a uniform intensity within the cross section of the beam (instead of a Gaussian profile) for simplifying your calculations.

Problem 7 (Blackbody Radiation): (0%)

The radiation that our Sun emits can be resembled to the radiation emitted by a blackbody with average surface temperature of 5505° C. If it is assumed that each planet of our solar system is at constant temperature (in thermodynamic equilibrium), and emits radiation as a blackbody what each planet mean temperature in degrees Kelvin? Take into account the average power reflection coefficient of the Sun radiation by each planet (its ***albedo***). Neglect the greenhouse effect, the planetary atmospheric pressure, and any other phenomenon that could contribute to the average planet temperature. All the data that are needed are shown in the following table:

	Average Radius (km)	**Average Distance from the Sun ($\times 10^6$ km)**	**Average *albedo***
Sun	695700	-	-
Mercury	2439.5	57.9	0.12
Venus	6052	108.2	0.75
Earth	6378	149.6	0.30
Mars	3396	227.9	0.16
Jupiter	71492	778.6	0.34
Saturn	60268	1433.5	0.34
Uranus	25559	2872.5	0.30
Neptune	24764	4495.1	0.29
Pluto	1185	5906.4	0.40

Problem 8 (Blackbody Radiation): (20%)

Unlike the Earth, the Moon has no atmosphere, so there is no greenhouse effect. Further, the dark side of the Moon is very cold, while the bright side is much warmer.

Consider two models for estimating surface temperatures on the bright side of the moon. Moon radius is 1737 km and Moon's distance from the Sun is 149.6×10^6 km (approximately the mean distance of Earth from the Sun). The radiation that our Sun emits can be resembled to the radiation emitted by a blackbody with average surface temperature of 5505° C. Sun radius is 695700 km.

(a) Assume that all the power in the sunlight which hits the Moon is radiated as thermal radiation emitted by the half of the Moon's surface which is in sunlight (its bright side). Estimate the temperature of the surface of the bright side of the Moon taking into account Moon's ***albedo*** which is assumed constant and equal to 0.120.

(b) The model of part (a) is not very realistic. There is no way for the entirety of the sunlit side of the moon to be kept at the same temperature. A better, and simpler, model considers that each individual spot on the Moon's surface collects some amount of power from the Sun and then emits all of that power in the form of thermal radiation. Therefore, consider a $1m^2$ area of the Moon's bright surface perpendicular to the Sun's rays and re-emits this energy in the form of thermal radiation. Again estimate the surface temperature of this area of the Moon taking into account the Moon's ***albedo.***

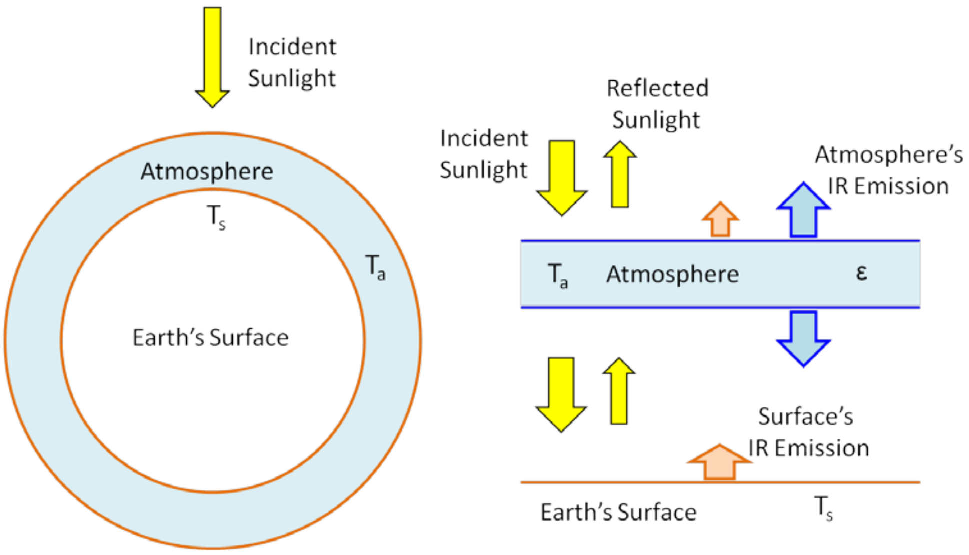
(This problem was taken from the internet and was slightly modified – Physics 121)

Problem 9 (Simple Model for Greenhouse Effect): (20%)

A single-layer atmosphere of a planet, like Earth, can be considered in order to demonstrate the basics of the greenhouse effect. The atmospheric layer is wrapped around the planet like an invisible blanket. In this simple model visible sunlight is assumed to pass through the atmosphere without any scattering or absorption (of course this is a crude approximation). The planetary ***albedo*** remains the same (assume to be **0.30** for Earth as it can be seen from the previous table) and surface net shortwave flux is the same as at the top of the atmosphere. The atmosphere only affects the infrared (IR) radiation flux emitted by the Earth's surface at equilibrium. A part of it is absorbed and heats the atmosphere, another part is transmitted and escapes into space. It is also assumed that the atmosphere behaves like a "grey body" with a constant emissivity (and absorptivity) of ε (independent of the freespace wavelength, and $0 < \varepsilon < 1$). In equilibrium assume that the Earth's surface temperature is T_s and that the atmospheric temperature is T_a (both are assumed constant in this simple model). A simple picture of the single-layer atmosphere and the corresponding radiation fluxes is shown in the figure below. It is given that the sun's radiation that is arriving at Earth, as measured from satellites outside Earth, is approximately $1360 W/m^2$.

(a) Calculate the Earth's surface temperature T_s and its atmospheric temperature T_a as functions of the emissivity ε.

(b) If it is known that the average Earth's surface temperature is 15°C what is the emissivity ε of the atmosphere?



Problem 10 (Photometric Quantities): (10%)

A particular Liquid-Crystal (LC) computer projector has a rated output of 1800 lumens. The LC projector produces equal luminous power in each of the three primary colors. The freespace wavelengths corresponding to the three primary colors are $\lambda_R = 670nm$ (for red color), $\lambda_G = 550nm$ (for green color), και $\lambda_B = 440nm$ (for blue color). For this projector calculate the radiant power (in watts) in each of its three primary colors and the total radiant power (in watts) that is emitted. Now assume that the projector illuminates a fully reflective screen of dimensions 1.80m × 1.20m. The reflective screen can be considered as a Lambertian source. In the latter case, find the luminance of the reflective screen in cd/m^2.

Problem 11 (Blackbody Color): (30%)

Calculate the chromaticity coordinates of an ideal blackbody radiator as a function of its temperature. Assume that the temperature range is between 1000 °K to 12000 °K in steps of 100 °K. For this problem the color matching functions, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$, are needed. These data can be found in url-link: http://www.cvrl.org . For convenience the same data are also available in class' web site in the following url-link: http://users.ntua.gr/eglytsis/OptEng/Color_matching_functions_2deg_CIE_1931.pdf .

(a) Make a plot of the chromaticity coordinates embedded in the CIE chromaticity diagram as a function of temperature of the blackbody radiator.

(b) Tabulate the chromaticity coordinates of a blackbody for T = 1000−10000 °K in steps of 1000 °K.

(c) Now it is desired to represent the perceived (by human eye) color of the blackbody as a function of its temperature. For this case the standard RGB will be utilized. For this standard the matrix $\widetilde{M}$ that converts X, Y, Z, tristimulus values to R, G, B values is given by

$$\tilde{M} = \begin{bmatrix} 3.2404542 & -1.5371385 & -0.4985314 \\ -0.9692660 & 1.8760108 & 0.0415560 \\ 0.0556434 & -0.2040259 & 1.0572252 \end{bmatrix}.$$

Since R, G, B should be in the range from 0 to 1 normalize the calculated R, G, B dividing them with their maximum. For better color perception a nonlinear correction is applied to the normalized R, G, B values which is given by

$$W' = \begin{cases} 12.92W & \text{for} \quad W < 0.0031308, \\ 1.055W^{1/2.4} - 0.055 & \text{for} \quad W \geq 0.0031308, \end{cases}$$

where W is any of R, G, B. The final R, G, B values should be clipped to zero if they are negative or clipped to one if they are above unity. Based on the above information try to represent the perceived color of a blackbody as a function of its temperature with and without the gamma correction.

Problem 12 (Blackbody Radiation – Human Body): (20%)

Assume that the average human body can be considered as a blackbody radiator with temperature of 36.6 Celsius and approximate surface of one square meter. (a) Make a graphical representation of the radiant emittance $M_\lambda(\lambda)$ in $W/m^2/\mu m$ (express wavelength axis in microns). For which wavelength is $M_\lambda(\lambda)$ maximum? (b) Find the total power that the human body emits between wavelengths of 10μm -10.1μm. What percentage of the total emitted power does it represent? How many photons per second does the human body emits (on the average) between 10μm -10.1μm? (c) Find the total power that the human body emits in the visible spectrum i.e., between wavelength of 0.38μm -0.78μm. What percentage of the total emitted power does it represent? How many photons per second does the human body emits (on the average) in the visible spectrum?