Optical detectors

The calculator is allowed, but any document is forbidden.

Duration : 1h30

Questions of course:

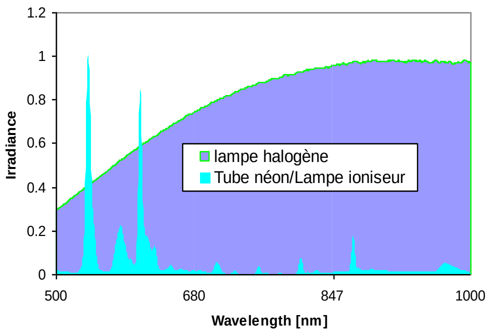
1. What is the wavelength range of the visible light? What are the minimum and the maximum energy of the photons?
2. Explain the concept of work function and give its relation to the threshold of the frequency of the incident light.

Comparison of two types of lamp

A neon tube lamp consumes 10 W of electricity and emits a radiation of 8 W and 800 lm of light (luminous flux). We want to compare the efficiency of the neon lamp and a halogen lamp. The two lamps radiate homogeneously in a half-space.

1. Calculate the radiant (electrical) efficiency and the luminous efficiency of the neon lamp. What then is its luminous intensity I_v (lm/sr)?
2. An halogen lamp emits the same luminous flux and we know that its luminous efficiency is 13.2 lm/W. How much is its radiant flux?
3. Deduce the irradiance (W/m^2) and the illuminance (lm/m^2) at 2 m from the two lamps. Compare their efficiency and explain the difference according the figure given bellow.
4. The halogen lamp can be regarded as a black body and it can support a maximum temperature of 3500 K. What then is the surface area of the filament to ensure this emission? Determine the wavelength of maximum emission.
5. A detector of 4 mm^2 is located 20 cm from the neon lamp. What is the radiant flux received by the detector when its surface is normal to the direction of light arriving on it. What is the received radiant flux if the detector is inclined at 60°? What is the radiant flux received by the detector from the halogen lamp in the same configuration?
6. To simplify the calculation, we assume that the neon lamp radiation is monochromatic. The equivalent wavelength is 0.54 µm. Calculate the energy of each photon and determine the number of photons per second received by the detector.
7. The quantum efficiency of the detector is 15%, deduce the current generated by the received radiant flux.

Constantes et formules



- **Constantes** :
  - Planck's Constant : $h = 6{,}62\times10^{-34}$ J.s ;
  - Velocity of light in the vacuum: $c = 3\times10^{8}$ m/s ;
  - Electron charge: $e = 1{,}6\times10^{-19}$ C ;
- **Formulas** :
  - Solid angle: $\Omega = 2\pi(1-\cos\alpha) = S/R^2$
  - Stefan's law: $F = \sigma S T^4$ where $\sigma = 5{,}67\cdot10^{-8}$ W.m$^{-2}\cdot$K^{-4}
  - Wien's law: $\lambda_{max}T = 2898$ µm.K

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Correction :

Questions du cours : (3+2 pts)

1. . (3 pts) The three model of light:
   a. Ray model/geometrical optics: light is described by rays,
      Examples: reflection on a mirror, or refraction on a surface (Snell's law).
   b. Wave model: light is electromagnetic wave of wavelength between 0.4 and 0.8 µm.
      Examples: diffraction of a wave by a slit, a hole or a grid; interference …
   c. Corpuscular (quantum) model: light is a wind of grains called "photon",
      Examples: photoelectric effect.
2. Work function is the minimum energy) needed to remove an electron from a solid W_s. It is related the threshold of light frequency ν by $W_s=h\nu$ where h is the plank constant.

Exo. I : (7 pts)

1. (1.5 pts) the illuminated area: $S= =\pi\times(7.5\times10^{-2})^2,=0.0177\ m^2$,

   The solid angle: $\Omega=S/d^2=\pi\times(7.5\times10^{-2})^2/1^2=0.0177$ sr
2. (2 pts) Luminous flux : $F_v=E_v \cdot S=55\ 000\times0.0177=973$ lum (1100 lum for 0.02 m^2).

   Luminous intensity: $I_v=F_v/\Omega=973/0.0177=55000$ lum/sr
3. (1.5 pts) Luminous efficiency of the bulb: $\kappa= 972/30 = 32$ lum/W
4. (2 pts) $\lambda_{max}=2897/T$

   $\lambda_{max,3700}=0.78$ µm, $\lambda_{max,4500}=0.64$ µm, $\lambda_{max,5000}=0.58$ µm,

Exo. III (8 pts) :

1. (2 pts) La fréquence : $\nu = c/\lambda = 7.06\times10^{14}$ (Hz), l'énergie : $E = h\,\nu = 4.67\times10^{-19}$ (J)
2. (1.5 pt) Nombre de photons/seconde : $n_p = P/E = 0.1/4.67\times10^{-19} = 2.14\times10^{17}$
3. (1.5 pt) Nombre de électrons/seconde : $n_e= I_{sat}/e = 0.005/1.6\times10^{-19} = 3.125\times10^{16}$
4. (1 pt) Quantum efficiency: $\varepsilon = n_e/n_p = 3.125\times10^{16} / 2.14\times10^{17} = 14.6\%$
5. (2 pts)Fréquence seuil : $\nu_s = W_s /h = 2\times1.6\times10^{-19} / 6.62\times10^{-34}=4.83\times10^{14}$ (Hz)

   $\lambda=c/\nu_s=0.62$ µm