Faculty of Sciences | Rouen University
21 December 2018 | Examination | M2 Cell Imaging

Optical detectors

The calculator is allowed, but any material is forbidden.

Duration : 1h30

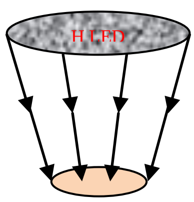
Questions of course:

1. What are the three models of light? Give a brief description of each model and an example of application.
2. Why do we use the two systems of physical quantities in photometry: radiant and luminous?

Exercise I. H LED based surgical lighting

H LED surgical light is a long-lasting light based on LED technology. It combines comfort, cost-savings, HD image integration and sustainable development for efficient use in the surgical suite. We propose to study some of its characteristics. The data sheet of a typical light is given below.

Type:	H LED 500
Diameter of light head:	58 cm
Illuminance:	140 000 lx
Field diameter at 1 m:	24 cm
Color temperature:	4 200 K
Light head consumption:	110 W



In the following calculation, we suppose that all the light emitted by the H LED light arrives on the illuminated field and the light is homogenous on the surfaces of the emitter and the receiver.

1. Calculate the total luminous flux (lm) on the illuminated field and the luminous emittance ($lx=lm/m^2$) of the light.
2. Assume that the electrical efficiency is 100%, determine the luminous efficacy of the light?
3. What is the wavelength of maximum emission corresponding to the color temperature if the LED light were considered as a black body?
4. We want to replace the H LED light by a tungsten lamp. The latter emits light homogeneously in all space. What total flux should be emitted by the lamp so that to obtain the same illuminance at 1 m? The electrical and luminous efficiencies are respectively 85 % and 15 lm/W. What power of the lamp should be used?

Exercise II. Efficiency of a detector

We propose to study the efficiency of a detector.

1. Suppose that a detector receives a radiant flux P at wavelength λ and generates a current I. We define the current response of the detector as function of wavelength by $R(\lambda) = I/P$. Express first the number of photons per second n_p in the flux and then show that the theoretical current responses is given by $R(\lambda) = e\lambda/hc$ (A/W), where the constants e, h and c are given in the appendix.
2. If the quantum efficiency is η, what is then the real response function of the detector?
3. The stop wavelength of a detector of Silicon is 1.0 µm. Deduce its work function?

K. F. Ren

4. If the detector is illuminated by a light beam of 30 mW and we suppose that the surface of the detector is large enough to receive all the flux of the beam. And we know the quantum efficiency is 0.1 for wavelength λ_1 = 0.5 µm and 0.8 for λ_2 = 0.9 µm. What is the current generated by the detector in the two cases?
5. What will happen if the detector is illuminated by far infrared radiation of wavelength λ = 5 µm.

Appendix
Constants and formulas

- **Constants** :
  - Constant of Planck : $h = 6{,}62\times10^{-34}$ J.s ;
  - Velocity of light in the vacuum: $c = 3\times10^{8}$ m/s ;
  - Charge of an electron : $e = 1{,}6\times10^{-19}$ C ;
- **Formules** :
  - Area of a circle : $A = \pi R^2$
  - Surface area of a sphere : $A = 4\pi R^2$
  - Stefan's law: $M = \sigma T^4$ où $\sigma = 5{,}67\cdot10^{-8}$ W.m$^{-2}\cdot$K^{-4}
  - Wien's Law : $\lambda_{max}T = 2898$ µm.K

Correction :

Questions :

1. Trois modèles :
   a. Optique géométrique : rayons lumineux ; formation d'image, réflexion, réfraction.
   b. Ondulatoire : ondes EM ; diffraction, interférence, …
   c. Corpusculaire : vent de photons ; effet photo-électrique, …
2. Voir le cours.

Exo. I : H LED based surgical lighting

http://www.medtechnica.co.il/files/Brocure%20-%20Sergury%20room/HLED.pdf

1. The total received flux: $F_{vr} = \pi d^2 E_{vr}/4 = \pi \times 0.12^2 \times 140000 = 6333$ lm,
   $E_{ve} = E_{vr} * d_r^2 / d_e^2 = 2397$ lx.
2. The luminous efficiency: $\kappa = 6333/110 = 57.6$ lm/W.
3. According to Wien's law : $\lambda_{max} = 2898/4200 = 0.69$ µm
4. The illuminance at 1 m: $E_{vr} = 140000$ lm/m^2 (lx). So $F_v = 4\pi E_{vr} = 1.3810^6$ lm
   $P = F_v/\kappa_T/\varepsilon = 1.3810^6/57.6/0.85 = 28684$ W

Exo. II : Efficiency

1. The number of phontons per second : $n_p = P/h\nu = P\lambda/hc$.
   The generated current is: $I = n_p e = P\lambda e/hc$
   So the current response : $R(\lambda) = e\lambda/hc$ (A/W)
2. If the quantum efficiency is η, the the current : $I = n_p \eta e = P\lambda e\eta/hc$, so $R(\lambda) = e\lambda\eta/hc$ (A/W).
3. The stop wavelength λ is related to the work function W_a by : $W_a = hc/\lambda$
4. The current response: $R(0.5) = \frac{1.6\times10^{-19}\times0.5\times10^{-6}}{6.62\times10^{-34}\times3\times10^{8}}\times0.1 = 0.04$ (A/W)

   $$R(0.9) = \frac{1.6\times10^{-19}\times0.9\times10^{-6}}{6.62\times10^{-34}\times3\times10^{8}}\times0.8 = 0.58 \text{ (A/W)}$$

   So the currents are respectively: $I(0.5) = 0.12$ mA and $I(0.9) = 17.4$ mA
5. No signal. If the flux is too strong, the detector may be destroyed.