Optics

Photons

Problem 1.- A YAG laser emits a pulse of infrared radiation that is converted to green light by a frequency doubler. The resulting pulse lasts t=9ns, has energy of 120mJ and wavelength of 532 nm.
Calculate:

a) The number of green photons emitted.
b) The total linear momentum of the pulse
c) The length of the pulse (in meters)
d) The frequency of the light.

Solution:
The number of green photons emitted. The total energy divided by the energy of one photon give us the number of photons:

$$N = \frac{\text{energy}}{\left(\frac{hc}{\lambda}\right)} = \frac{120\times10^{-3}\,\text{J}}{\left(\frac{(6.62\times10^{-34}\,\text{Js})(3\times10^{8}\,\text{m/s})}{532\times10^{-9}\,\text{m}}\right)} = \mathbf{3.21\times10^{17}}$$

The total momentum of the pulse: Notice that for photons energy=pc, so the momentum is the energy divided by the speed of light:

$$p = \frac{\text{energy}}{c} = \frac{120\times10^{-3}\,\text{J}}{3\times10^{8}\,\text{m/s}} = \mathbf{4\times10^{-10}\,kg\ m/s}$$

The length of the pulse: Using the speed of light and the time of the pulse:

$$\text{length} = ct = \left(3\times10^{8}\,\text{m/s}\right)\left(9\times10^{-9}\,\text{s}\right) = \mathbf{2.7\ m}$$

The frequency of the light: The fundamental equation of waves. What is new? c over lambda.

$$f = \frac{c}{\lambda} = \frac{3\times10^{8}\,\text{m/s}}{532\times10^{-9}\,\text{m}} = \mathbf{5.6\times10^{14}\,Hz}$$

Problem 2.- Approximate number of photons in a 10fs pulse of 600 nm wavelength light from a 1kW peak power laser.

(A) 3×10^{3}
(B) 3×10^{7}
(C) 3×10^{11}
(D) 3×10^{15}
(E) 3×10^{18}

Solution: The total energy is: $E = power \times time$ and the energy of 1 photon is $E_1 = hc/\lambda$, so the number of photons will be:

$$N = \frac{power \times time \times \lambda}{hc} = \frac{1000 \times 10 \times 10^{-15} \times 600 \times 10^{-9}}{6.62 \times 10^{-34} \times 3 \times 10^{8}} = 3 \times 10^{7}$$

Answer (B)

Problem 3.- Calculate the number of photons produced each second by a He-Ne laser rated 5mW.

Solution: In one second the energy in the beam will be 0.005 joules and to get the number of photons we divide by the energy of one:

$$\frac{0.005}{hc/\lambda} = \frac{0.005\lambda}{hc} = \frac{0.005 \times 633 \times 10^{-9}}{6.62 \times 10^{-34} \times 3 \times 10^{8}} = \mathbf{1.6 \times 10^{16}}$$

Problem 4.- A He-Ne laser emits light at a rate of 1.5mW at a wavelength of 632 nm.
Calculate:

a) The number of photons emitted per second.
b) The linear momentum per second that the source emits.

Solution:

The energy of 1 photon is: $E_1 = \frac{hc}{\lambda} = \frac{(6.62 \times 10^{-34})(3 \times 10^{8})}{632 \times 10^{-9}} = 3.14 \times 10^{-19}$ J

And the laser emits 1.5 mJ per second, so the number of photons is:

$$N = \frac{1.5 \times 10^{-3}}{3.14 \times 10^{-19}} = \mathbf{4.77 \times 10^{15}}$$

The linear momentum is $p = \frac{E}{c} = \frac{1.5 \times 10^{-3}}{3 \times 10^{8}} = \mathbf{5 \times 10^{-12}}$ **kgm/s**