Solution:

From Example 1.1, the photon energy of the 700 nm wavelength at the red end is $h\nu_{\mathrm{red}} = 1.77$ eV, and that of the 400 nm wavelength at the violet end is $h\nu_{\mathrm{violet}} = 3.10$ eV. Therefore, the photon flux of a beam that has a power of $P = 1$ W at the 700 nm red wavelength is

$$\text{red photon flux} = \frac{P}{h\nu_{\mathrm{red}}} = \frac{1}{1.77 \times 1.6 \times 10^{-19}}\ \mathrm{s}^{-1} = 3.53 \times 10^{18}\ \mathrm{s}^{-1},$$

and the photon flux of a beam that has a power of $P = 1$ W at the 400 nm violet wavelength is

$$\text{violet photon flux} = \frac{P}{h\nu_{\mathrm{violet}}} = \frac{1}{3.10 \times 1.6 \times 10^{-19}}\ \mathrm{s}^{-1} = 2.02 \times 10^{18}\ \mathrm{s}^{-1}.$$

The momentum carried by a red photon is

$$p_{\mathrm{red}} = \frac{h\nu_{\mathrm{red}}}{c} = \frac{1.77 \times 1.6 \times 10^{-19}}{3 \times 10^{8}}\ \mathrm{N\,s} = 9.44 \times 10^{-28}\ \mathrm{N\,s},$$

and that carried by a violet photon is

$$p_{\mathrm{violet}} = \frac{h\nu_{\mathrm{violet}}}{c} = \frac{3.10 \times 1.6 \times 10^{-19}}{3 \times 10^{8}}\ \mathrm{N\,s} = 1.65 \times 10^{-27}\ \mathrm{N\,s}.$$

The total momentum carried by an optical beam that has a power of P during a time duration of Δt is independent of the optical wavelength:

$$\text{total momentum} = (\text{photon flux})p\Delta t = \frac{P}{h\nu} \cdot \frac{h\nu}{c}\Delta t = \frac{P\Delta t}{c}.$$

Therefore, irrespective of whether the wavelength of the beam is at the red or the violet end, the total momentum carried by the beam in a time duration of $\Delta t = 1$ s is

$$\text{total momentum} = \frac{P\Delta t}{c} = \frac{1 \times 1}{3 \times 10^{8}} = 3.33 \times 10^{-9}\ \mathrm{N}.$$

1.1.2 Wave Nature of Light

An optical wave is characterized by the space and time dependence of the optical field, which is composed of coupled electric and magnetic fields governed by Maxwell's equations. It varies with time at an optical carrier frequency, and it propagates in a spatial direction determined by a wavevector. The behavior of an optical wave is strongly dependent on the optical properties of the medium. An optical field is a vectorial field characterized by five parameters: polarization, magnitude, phase, wavevector, and frequency. Polarization and wavevector are vectorial quantities; magnitude, frequency, and phase are scalar quantities. The general properties of optical fields are described in the following sections.