02. Concepts and Principles 2

Momentum of Electromagnetic Waves

Just as electromagnetic waves involve the flow of energy, they also carry momentum in the direction of motion. Although it may seem confusing that mass-less, non-material fields, or at least changes in these fields, can have momentum, the momentum carried by electromagnetic waves can be directly measured. The long tail of a comet, pointing directly away from the sun, is a result of the momentum carried by the sun's electromagnetic waves.

The simplest phenomenon directly involving the momentum of electromagnetic waves occurs when the waves are absorbed or scattered from an object. Since the wave has momentum, some of this momentum is transferred to the object the wave "collides" with. This interaction can be directly studied by applying conservation of momentum, but an easier shortcut involves defining the concept of *radiation pressure*. Radiation pressure is the force per unit area that the wave exerts on the object during the collision. Radiation pressure is defined as:

pic 15

where a is a number between 1 and 2 that depends on the portion of the electromagnetic wave absorbed during the collision. If the wave if fully absorbed, a = 1. If the wave is perfectly reflected, a = 2. (We won't analyze situations between these two extremes.)

Polarization of Electromagnetic Waves

In many cases, the electric field component of an electromagnetic wave oscillates in a well-defined direction. When this is the case, the wave is said to be *polarized*. The polarization direction is the direction in which the electric field oscillates. For example, in the diagram below the wave is polarized in the y-direction.

pic 16

Certain materials allow only one specific directoin of electric field vector to progagate through them. These materials, called *polarizers*, typically absorb (or reflect) all waves with electric field vectors not aligned with their transmission axis. For example, a polarizer with transmission axis along the +x-direction would completely block the propagation of the wave illustrated above.

If the incident electric field vectors is not perfectly aligned with the transmission axis, only the component of the field vector along the transmission axis can pass through the polarizer. Thus the electric field magnitude that passes through the polarizer, E, is given by:

pic 17

where

- E_0 is the electric field magnitude incident on the polarizer,
- and q is the angle between the incident polarization direction and the transmission axis.

After passing through the polarizer, the electromagnetic wave is now polarized along the transmission axis.

Rather than concentrating on the electric field magnitude, in most cases its more useful to focus on the intensity of the wave. Since the average intensity of the wave is given by

pic 18

the intensity is proportional to the square of the electric field vector. Thus, a more useful version of the polarization equation is:

pic 19

where

- S_0 is the intensity incident on the polarizer,
- and q is the angle between the incident polarization direction and the transmission axis.

Interference of Electromagnetic Waves

Since electromagnetic waves consist of alternating electric and magnetic field vectors, if two or more waves pass through the same point in space (at the same time) their field vectors must add according to the basic principles of vector addition. This combination of waves through the vector addition of their field vectors is called *interference.*

In general, the interference of two electromagnetic waves can be incredibly difficult to analyze. We will restrict ourselves to a specific sub-class of interference phenomenon, in which there are only two sources of waves and the two sources produce waves of exactly the same frequency perfectly in phase. Typically, the easiest way to accomplish this is by having a single source of waves and then somehow dividing the waves and sending each portion of the wave along a separate path to a final common location. (This is a lot simpler than it sounds.)

The interference that results when the two waves are recombined depends only on the *path length difference*, Dd, the waves traveled to reach the recombination location. The path length difference is, as the name implies, simply the difference between the distance traveled by wave #1 and the distance traveled by wave #2 between separation and recombination,

pic 20

If this difference is exactly equal to zero, one wavelength, or any integer number of wavelengths, the waves will be perfectly in phase when they recombine and exhibit *constructive interference*, resulting in a locally maximum value for the electric field vector. Therefore, for constructive interference:

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where m is zero or any integer.

If the path length difference is exactly equal to one-half a wavelength, or any half-integer number of wavelengths, the waves will be perfectly out of phase when they recombine and exhibit *destructive interference*, resulting in a locally minimum value for the electric field vector. Therefore, for destructive interference:

pic 22

where m is zero or any integer.

Paul D'Alessandris (Monroe Community College)