Introduction: Light & Optics

Unit: Light & Optics

Topics covered in this chapter:

This chapter discusses the behavior and our perception of light.

- *Electromagnetic Waves* discusses properties and equations that are specific to electromagnetic waves (including light).
- *Color* discusses properties of visible light and how we perceive it.
- *Reflection* and *Mirrors* discuss properties of flat and curved mirrors and steps for drawing ray tracing diagrams.
- *Refraction* and *Lenses* discuss properties of convex and concave lenses and steps for drawing ray tracing diagrams.
- *Polarization, Diffraction,* and *Scattering* discuss specific optical properties of light.

One of the new skills learned in this chapter is visualizing and drawing representations of how light is affected as it is reflected off a mirror or refracted by a lens. This can be challenging because the behavior of the light rays and the size and location of the image changes depending on the location of the object relative to the focal point of the mirror or lens. Another challenge is drawing precise, to-scale ray tracing drawings such that you can use the drawings to accurately determine properties of the image, or of the mirror or lens.

Standards addressed in this chapter:

Massachusetts Curriculum Frameworks (2016):

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

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AP® Physics 2 Learning Objectives/Essential Knowledge (2024):

13.1.A: Describe light as a ray.

13.1.A.1: A light ray is a straight line that is perpendicular to the wavefront of a light wave and points in the direction of travel of the wave.

13.1.A.1.i: Light rays can be used to determine the behavior of light in geometric optics, where the wave nature of light can be neglected.

13.1.A.1.ii: Rays are not sufficient to understand the spreading of light. In interference and diffraction, the wave nature of the light is important.

13.1.A.1.iii: A laser is a common source of a single coherent, monochromatic beam of light that can be modeled as a ray.

13.1.A.2: Ray diagrams depict the path of light before and after an interaction with matter.

13.1.B: Describe the reflection of light from a surface.

13.1.B.1: Light that is incident on a surface can be reflected.

13.1.B.2: The law of reflection states that the angle between the incident ray and the normal (the line perpendicular to the surface) is equal to the angle between the reflected ray and the normal.

13.1.B.3: Diffuse reflection is the reflection of light from a rough surface and results in light reflected in many different directions, because the line normal to the surface varies over the area over which the light is incident.

13.1.B.4: Specular reflection is the reflection of light from a smooth surface and results in light uniformly reflected from the surface, because the line normal to the surface has an approximately constant direction over the area the light strikes.

13.2.A: Describe the image formed by a mirror.

13.2.A.1: Incident light rays parallel to the principal axis of a concave (converging) mirror will be reflected toward a common location, called the focal point.

13.2.A.2: Incident light rays parallel to the principal axis of a convex (diverging) mirror will be reflected such that they appear to have originated from a common location behind the mirror, called the focal point.

13.2.A.3: The focal point of a plane mirror is an infinite distance from the mirror.

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13.2.A.4: The focal point of a spherical mirror may be approximated as a point located on the principal axis of the mirror halfway between the surface of the mirror and the center of the mirror's radius of curvature.

13.2.A.5: A real image is formed by a mirror when light rays emanating from a common point are reflected and then intersect at a common point.

13.2.A.6: A virtual image is formed by a mirror when reflected light rays diverge such that they appear to have originated from a common point.

13.2.A.7: The location of an image depends on the focal length of the mirror and the distance between the object and the surface of the mirror.

13.2.A.7.i: The locations of a mirror's focal point, an object near the mirror, and the image of the object formed by the mirror follow sign conventions that are used to determine those locations relative to the mirror itself.

13.2.A.7.ii: The distance between the image formed and a plane mirror is equal to the distance between the object and the plane mirror.

13.2.A.8: The magnification of an image formed by a mirror is the ratio of the size of the image produced to the size of the object itself and depends on the locations of the object and image relative to the mirror.

13.2.A.9: Ray diagrams can be used to determine the location, type, size, and orientation of images formed by mirrors.

13.2.A.9.i: The three principal rays are typically used to find the images formed by mirrors. The principal rays are 1) the ray parallel to the principal axis, 2) the ray that reflects at the center of the mirror where the principal axis intersects the mirror, and 3) the ray that passes through the focal point of the mirror.

13.2.A.9.ii: Images formed by a mirror can be upright or inverted, virtual or real, and reduced, enlarged, or the same size as the object.

13.3.A: Describe the refraction of light between two media.

13.3.A.1: Refraction is the change in direction of a light ray as the ray passes from one medium into another.

13.3.A.2: Refraction is a result of the speed of light changing when light enters a new medium.

13.3.A.3: The index of refraction of a given medium is inversely proportional to the speed of light in the medium.

13.3.A.4: Snell's law relates the angles of incidence and refraction of a light ray passing from one medium into another to the indices of refraction of the two media.

13.3.A.4.i: When a light ray travels from a medium with a higher index of refraction into a medium with a lower index of refraction, the ray refracts away from the normal.

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13.3.A.4.ii: When a light ray travels from a medium with a lower index of refraction into a medium with a higher index of refraction, the ray refracts toward the normal.

13.3.A.4.iii: When a light ray is incident along the normal to a surface, the transmitted ray is not refracted.

13.3.A.5: Total internal reflection may occur when light passes from one medium into another medium with a lower index of refraction.

13.3.A.5.i: Total internal reflection of light occurs beyond a critical angle of incidence.

13.3.A.5.ii: For incident rays at the critical angle, the ray refracts at 90 degrees and travels along the surface of the material.

13.3.A.5.iii: For incident rays beyond the critical angle, all light is reflected (no light is transmitted into the other medium).

13.4.A: Describe the image formed by a lens.

13.4.A.1: Incident light rays parallel to the principal axis of a thin convex (converging) lens will be refracted and converge toward a common location on the transmitted side of the lens, called the focal point.

13.4.A.2: Incident light rays parallel to the principal axis of a thin concave (diverging) lens will be refracted and diverge as if they originated from a focal point on the incident side of the lens.

13.4.A.3: A real image is formed by a lens when light rays originating from a common point are refracted such that they intersect at another common point.

13.4.A.4: A virtual image is formed by a lens when refracted light rays diverge such that they appear to have originated from a common point.

13.4.A.5: For a thin lens, the location of an image depends on the focal length of the lens and the distance between the object and the midline of the lens, as given by the thin-lens equation.

13.4.A.5.i: The locations of a lens's focal point, an object, and the image of the object formed by the lens follow sign conventions that are used to determine those locations relative to the lens itself.

13.4.A.5.ii: Lenses have a focal point on both sides of the lens that depends on the shape of the respective side of the lens.

13.4.A.6: For a thin lens, the magnification of an image is the ratio of the size of the image produced to the size of the object itself and depends on the locations of the object and image relative to the lens.

13.4.A.7: Ray diagrams can be used to determine the location, type, size, and orientation of images formed by lenses.

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13.4.A.7.i: The three principal rays are typically used to find the images formed by lenses. The principal rays are 1) the ray parallel to the principal axis, 2) the ray that passes through the center of the lens where the principal axis intersects the lens, and 3) the ray that passes through the focal point of the lens.

13.4.A.7.ii: Images formed by a lens can be upright or inverted, virtual or real, and reduced, enlarged, or the same size as the object.

14.4.A: Describe the properties of an electromagnetic wave.

14.4.A.1: Electromagnetic waves consist of oscillating electric and magnetic fields that are mutually perpendicular.

14.4.A.1.i: Electromagnetic waves are transverse waves because the oscillations of the electric and magnetic fields are perpendicular to the direction of propagation.

14.4.A.1.ii: Electromagnetic waves are commonly assumed to be plane waves, which are characterized by planar wave fronts.

14.4.A.2: Electromagnetic waves do not need a medium through which to propagate.

14.4.A.3: Categories of electromagnetic waves are characterized by their wavelengths.

14.4.A.3.i: Categories of electromagnetic waves include (in order of decreasing wavelength, spanning a range from kilometers to picometers) radio waves, microwaves, infrared, visible, ultraviolet, X-rays, and gamma rays.

14.4.A.3.ii: Visible electromagnetic waves are further broken into categories of color, including (in order of decreasing wavelength) red, orange, yellow, green, blue, and violet.

14.4.A.3.iii: Visible electromagnetic waves are also called light. Sometimes, electromagnetic waves of all wavelengths are collectively referred to as light or electromagnetic radiation.

Skills learned & applied in this chapter:

- Drawing ray diagrams from mirrors and through lenses.