Light I

Physics 2415 Lecture 31

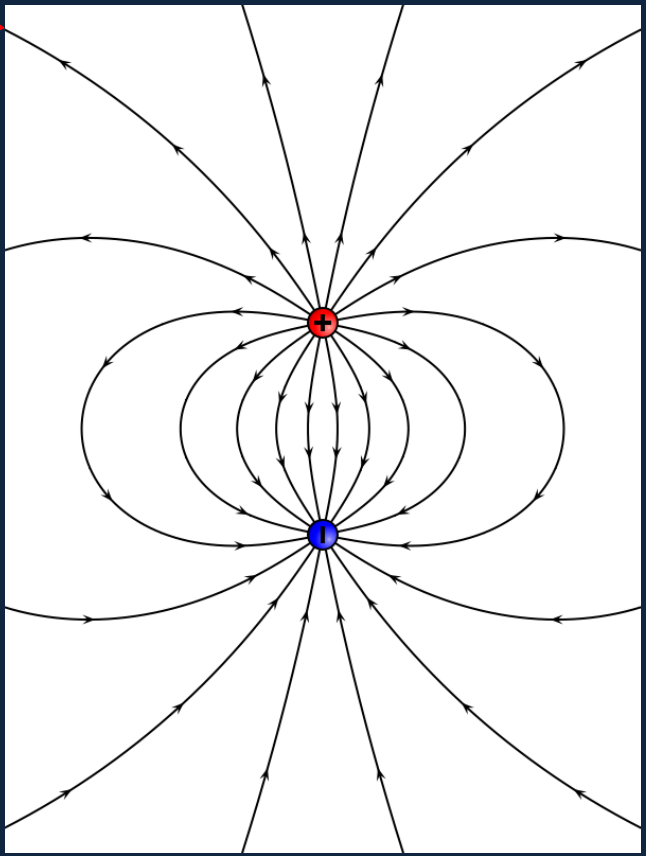
Michael Fowler, UVa

Today’s Topics

- Dipole radiation
- Photons
- Reflection and image formation by a plane mirror
- Concave and convex mirrors

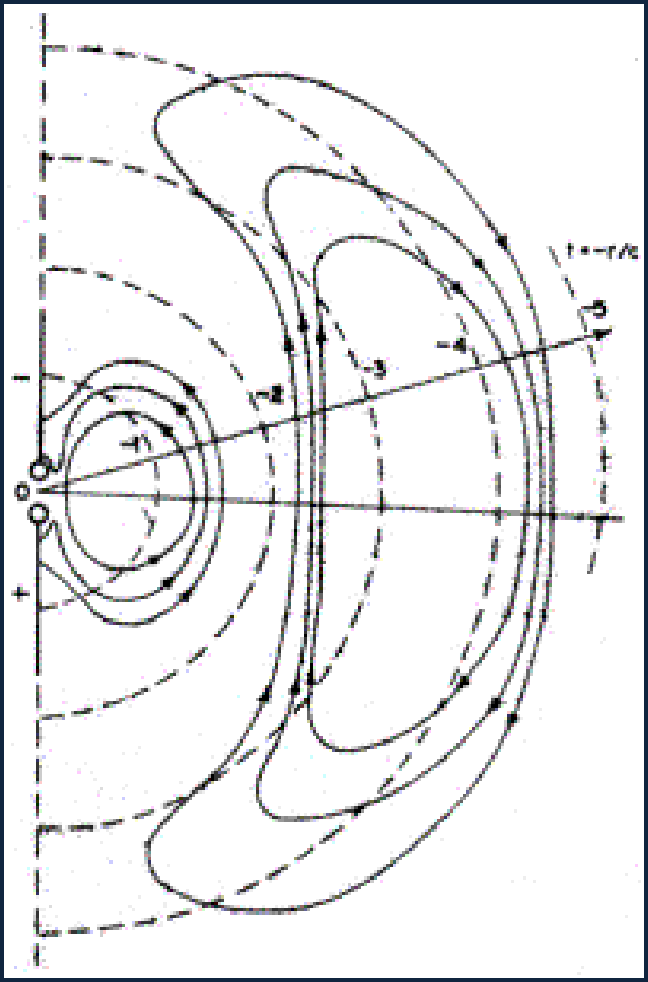
Dipole Radiation

- A static dipole field looks like this
- If the dipole is suddenly switched on (by pulling apart a + charge and - charge initially on top of each other) this field will propagate outwards.
- In a transmitter, the + and – charges move in simple harmonic motion, the dipole is constantly going to zero then switching sign, so the outgoing field is always changing.



Radio Transmission

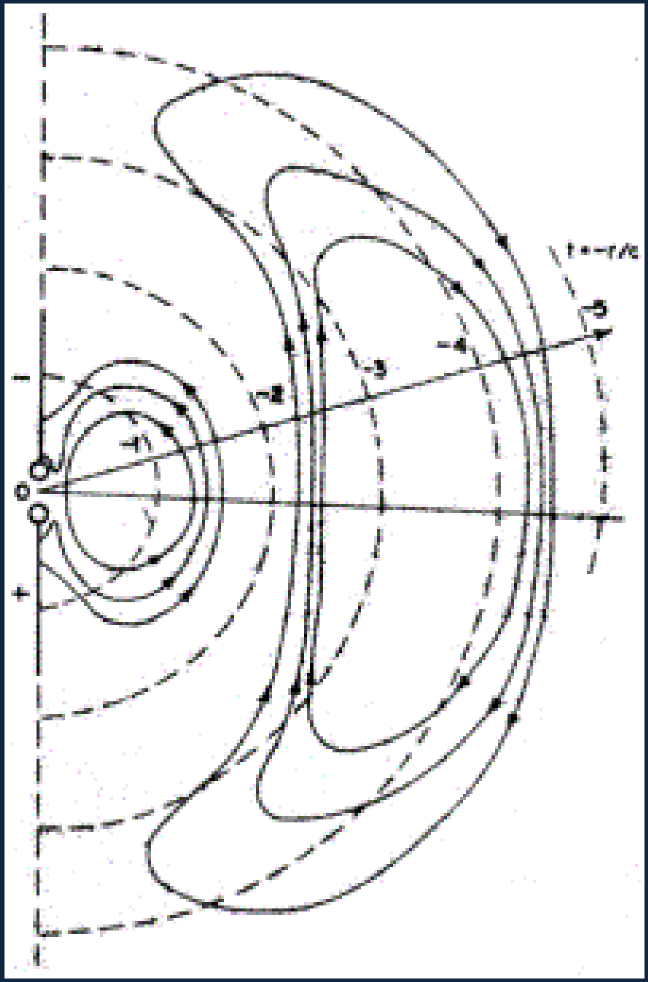
- The basic radio transmitter is an oscillating dipole: at some instant, a dipole is created, its field propagates outwards, but it rapidly dies to be replaced by a dipole in the opposite direction—the outgoing electric field must switch direction, it does this by looping around as seen here. The magnetic field lines from current up and down the dipole antenna are circular.



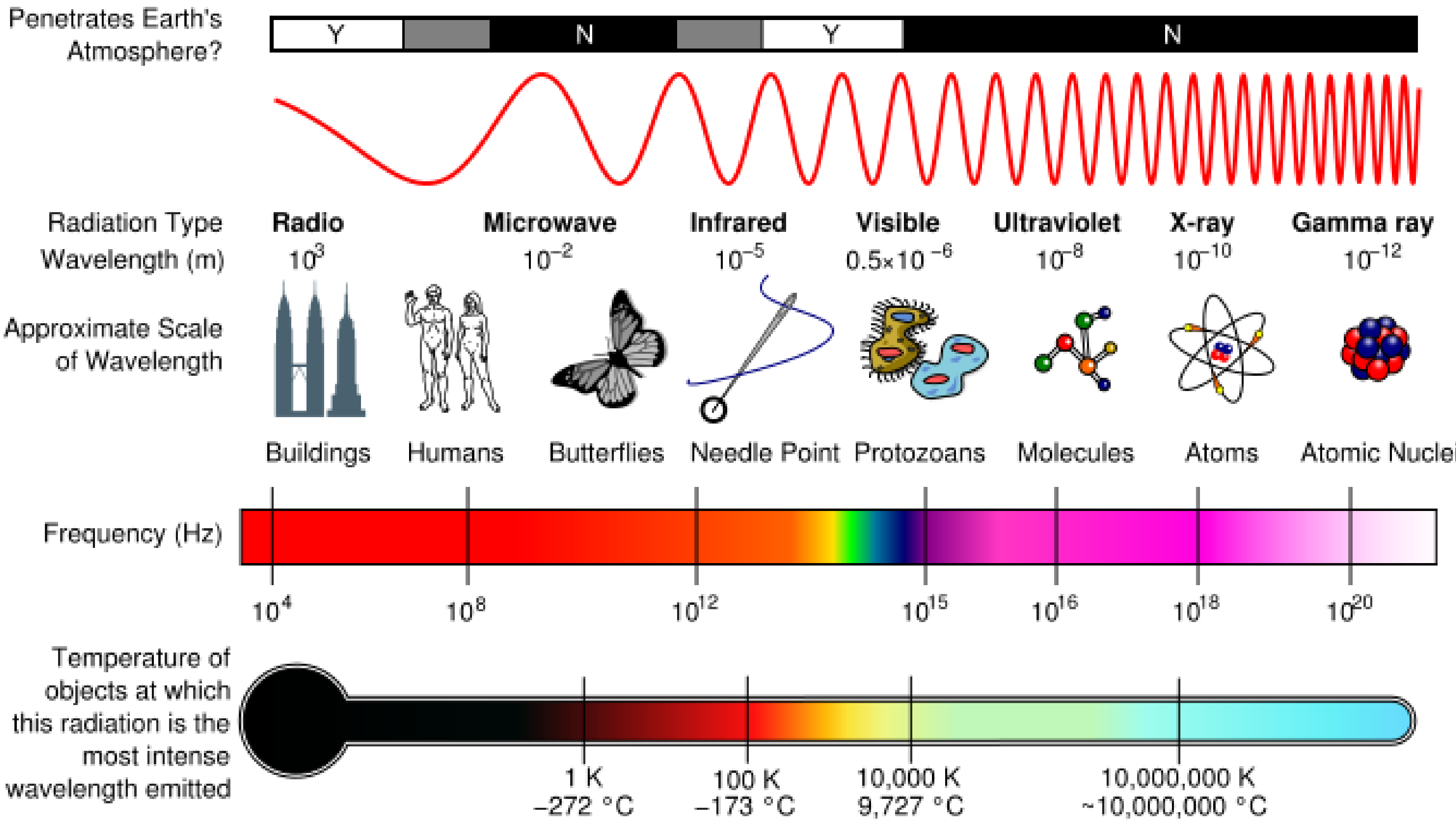
Some animations

Dipole Transmission

- Notice there is no radiation in the direction the dipole is pointing, it's mostly near the "equatorial" direction.
- At any point P, the electric field vector is in the plane containing P and the line of the dipole.
- Dipole radiation of light from atoms, and of X-rays from nuclei, have the same pattern.



Some animations


Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Radio
10^3
Microwave
10^{-2}
Infrared
10^{-5}
Visible
0.5×10^{-6}
Ultraviolet
10^{-8}
X-ray
10^{-10}
Gamma ray
10^{-12}
Approximate Scale of Wavelength
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

Light is a Wave…

but it doesn’t act much like one!

- Newton believed light was a stream of tiny particles—it goes in straight lines, leaves sharp shadows, doesn’t spread round corners like sound waves do.
- So how can a wave do that?

Beams of Sound Waves?

- Low frequency notes fill a room, it's difficult to localize their origin—this sound spreads around. You can put a woofer anywhere.
- High frequency notes come more directly out from a speaker—and don't go around corners so well.
- Ultrasound (10^7Hz) is extremely directional—a narrow beam can be used to image body parts well below 1 mm.
- Bottom line: the shorter the wavelength, the more beamlike.

Beams of Light

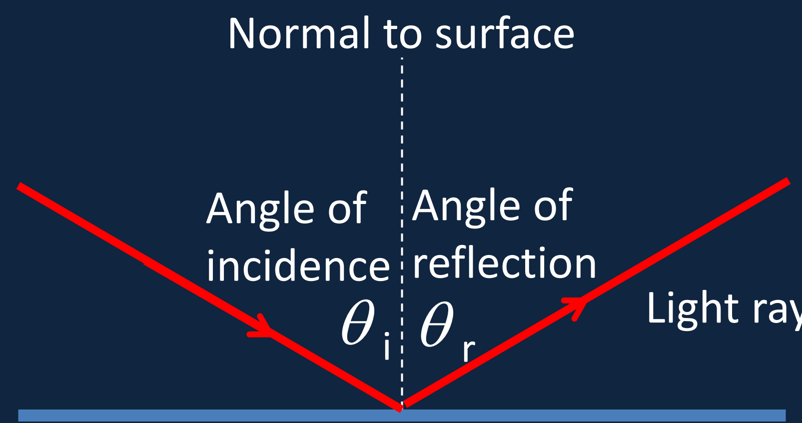
- The wavelength of light is a factor of 100 smaller than the ultrasound—so light travels in very tight beams over long distances.
- In analyzing light propagation, reflection and refraction, we shall discuss beams or rays of light which act just like streams of very fast particles.
- The wavelike properties of light can be detected, but it takes careful experimenting—they are certainly not obvious to the ordinary observer.

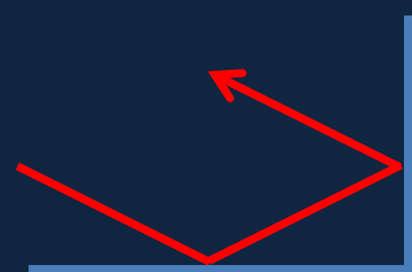
Photons

- Light propagates like a very short wavelength wave—but when it is absorbed, it behaves like a rain of particles! (This is quantum theory.)
- Electromagnetic waves of frequency f act on absorption as if they are composed of particles, called quanta or photons, of energy hf, where $h = 6.63 \times 10^{-34}$ J.sec is Planck's constant.
- This is why UV light can do you more damage than even very bright visible light, and why cell phone radiation is almost certainly safe.

Reflection from Plane Mirrors

- Just to remind you of the notation.
- 3-D corner reflectors (three planes like three sides of a cube) reflect a ray back from any angle.
- There's one on the Moon—the best proof that the Moon landing wasn't a hoax!

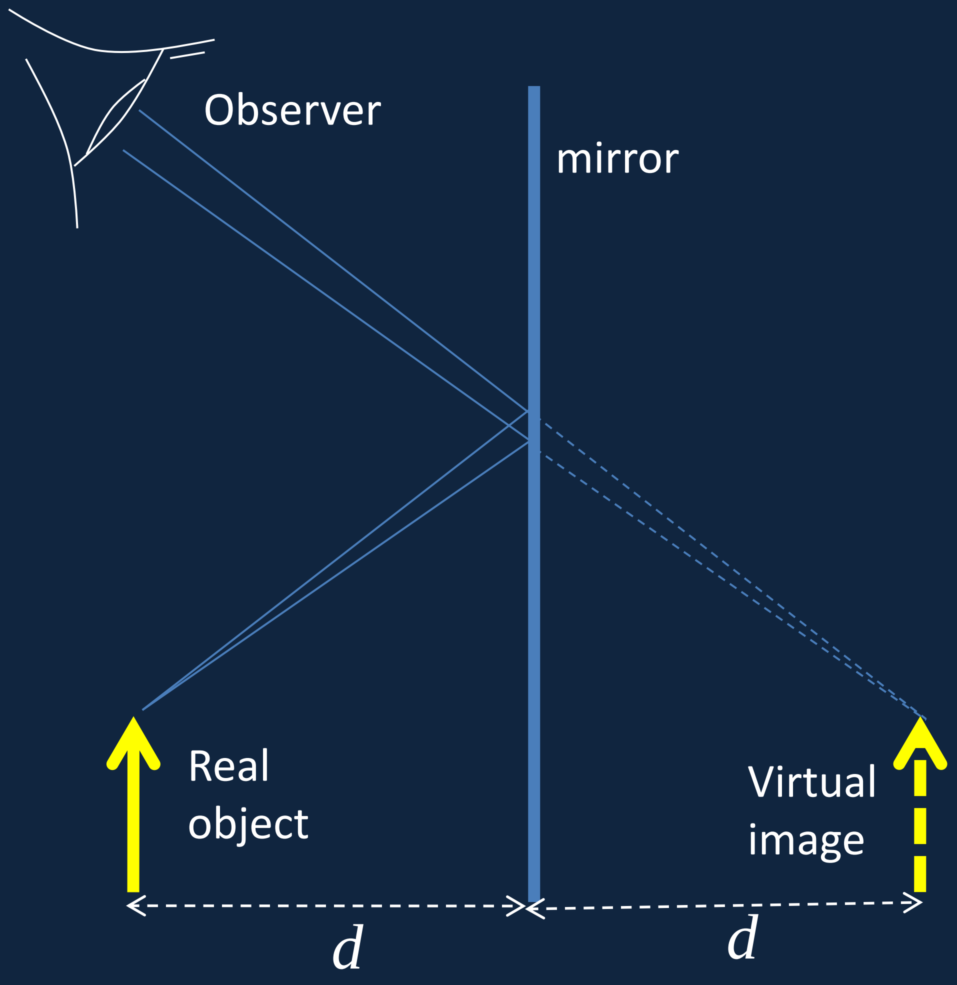




Corner retroreflector: the outgoing ray is always antiparallel to the ingoing ray.

Formation of an Image by a Plane Mirror

- The diverging rays from any point on the object, after reflection by a plane mirror, appear to diverge from a point *behind* the mirror as shown.
- The observer sees a virtual image—light rays do not actually come from that point behind the mirror!

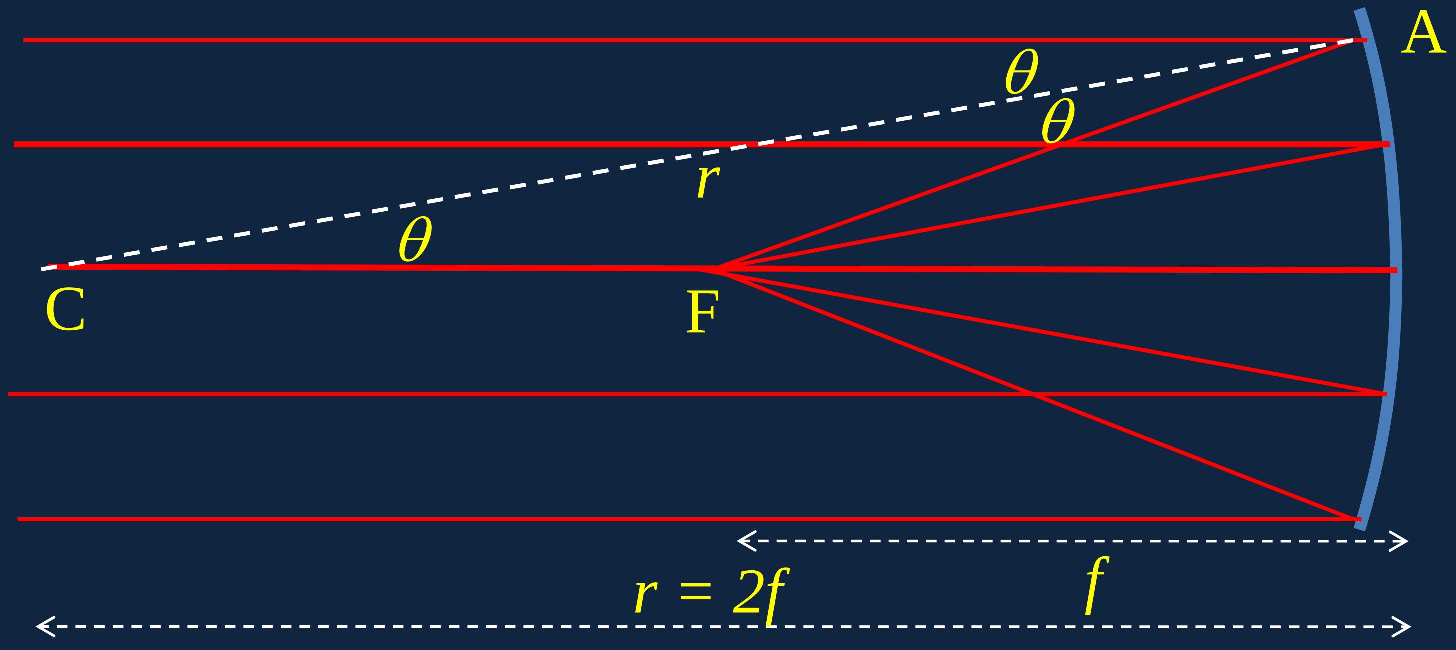


Question

- An image in a plane mirror has left and right reversed.
- How is that possible without also having up and down reversed?
- What if you look at your reflection while lying down sideways?

Concave Mirror: Focal Point

- A spherical concave mirror will, to a good approximation, focus all ingoing rays parallel to its axis to a single point, the focus, half the distance of the center of curvature from the center of the mirror:
- To see this. look at the isoceles triangle CAF:



Spherical Mirror Image Formation

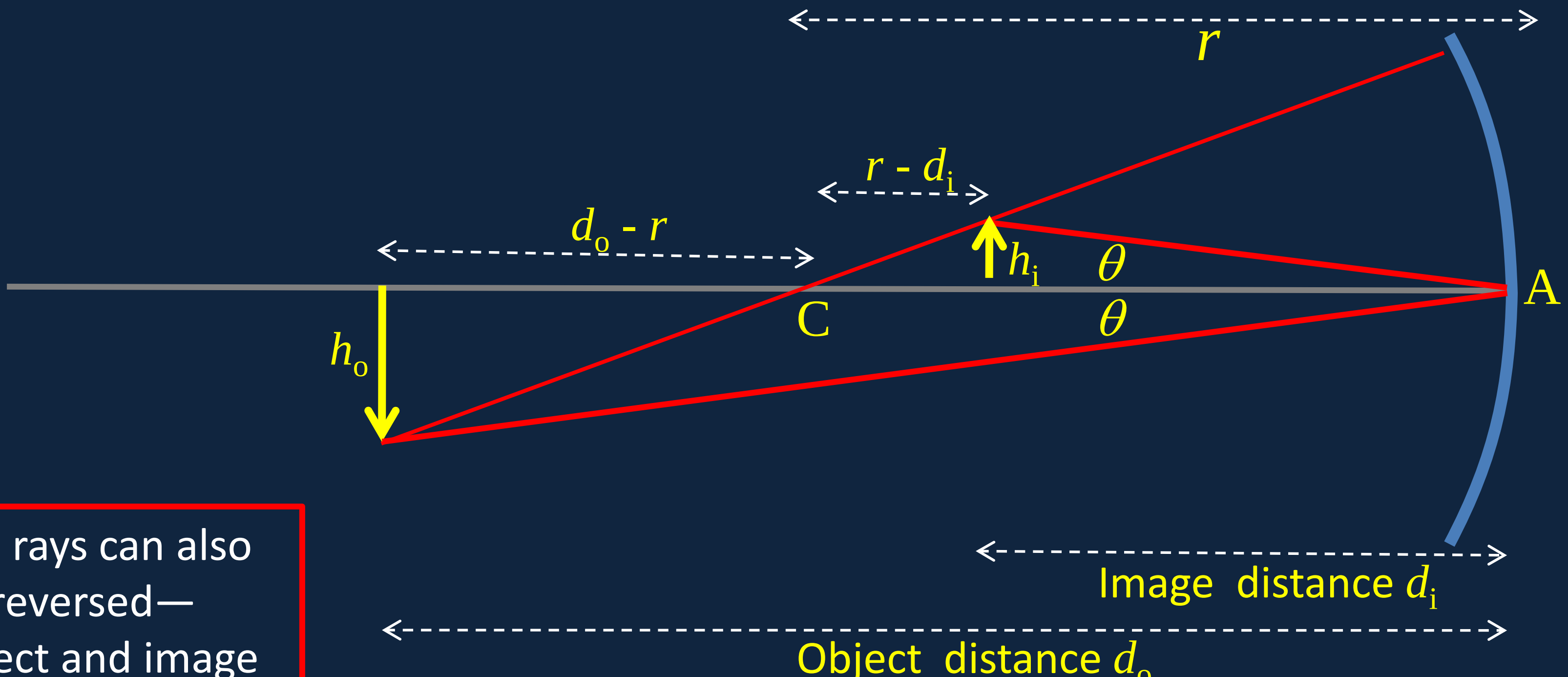
- We have seen that all rays from far away and parallel to the axis are reflected to one point, the focus, for a mirror which is a small part of a sphere.
- It can be proved (but we won't do it) that for such a mirror, all rays from one point (the "object") on reflection either all go to one point (real image) or apparently diverge from a point behind the mirror (virtual image).

Locating the Image

- Since all rays from the object go to the image, we only need to follow two different rays to locate the image.
- One simple ray is the one through the center of curvature of the mirror: it is reflected back along itself, since it hits the mirror normal to the surface.
- Another simple ray is the one striking the center of the mirror, which will be reflected as from a plane mirror (same angle with axis).

Real Image for Concave Mirror

- Drawing the ray through the center of curvature, and the ray striking the center of the mirror, (for an object beyond C):



The rays can also be reversed—object and image interchanged!

Finding the Image Distance

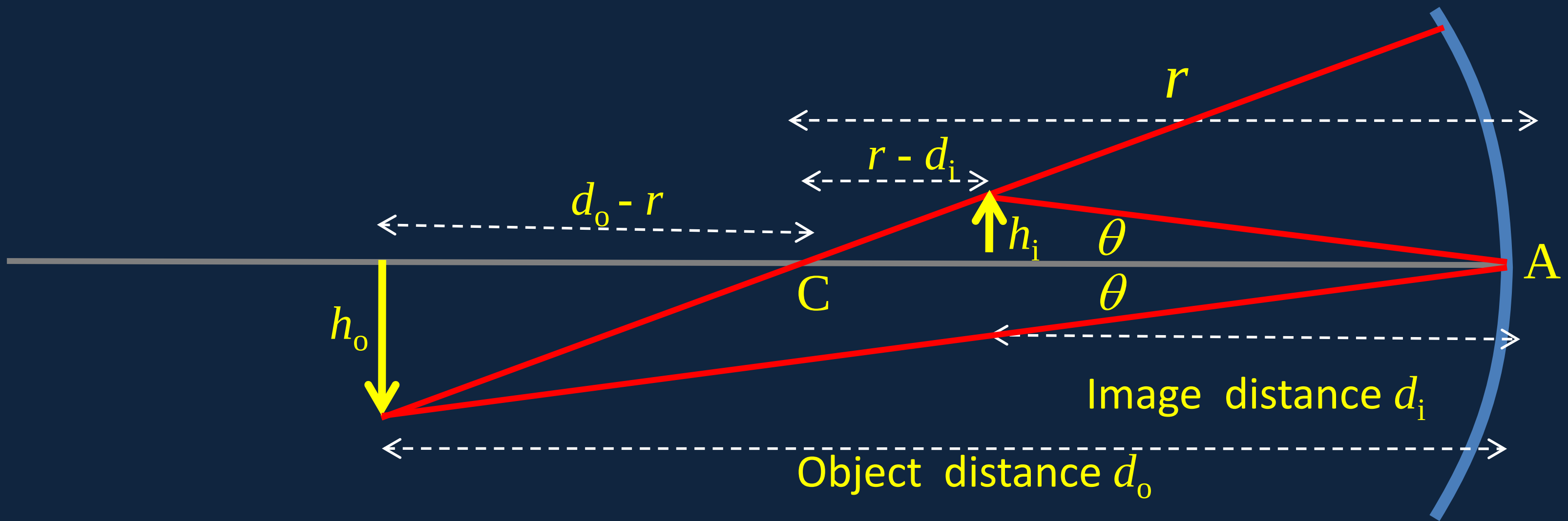
- The two triangles with angle θ are similar, so

$$h_o / h_i = d_o / d_i$$

- the two triangles with a corner at C are also similar,

$$\frac{h_o}{h_i} = \frac{d_o - r}{r - d_i} = \frac{d_o}{d_i}, \quad d_o r - d_o d_i = d_o d_i - r d_i$$

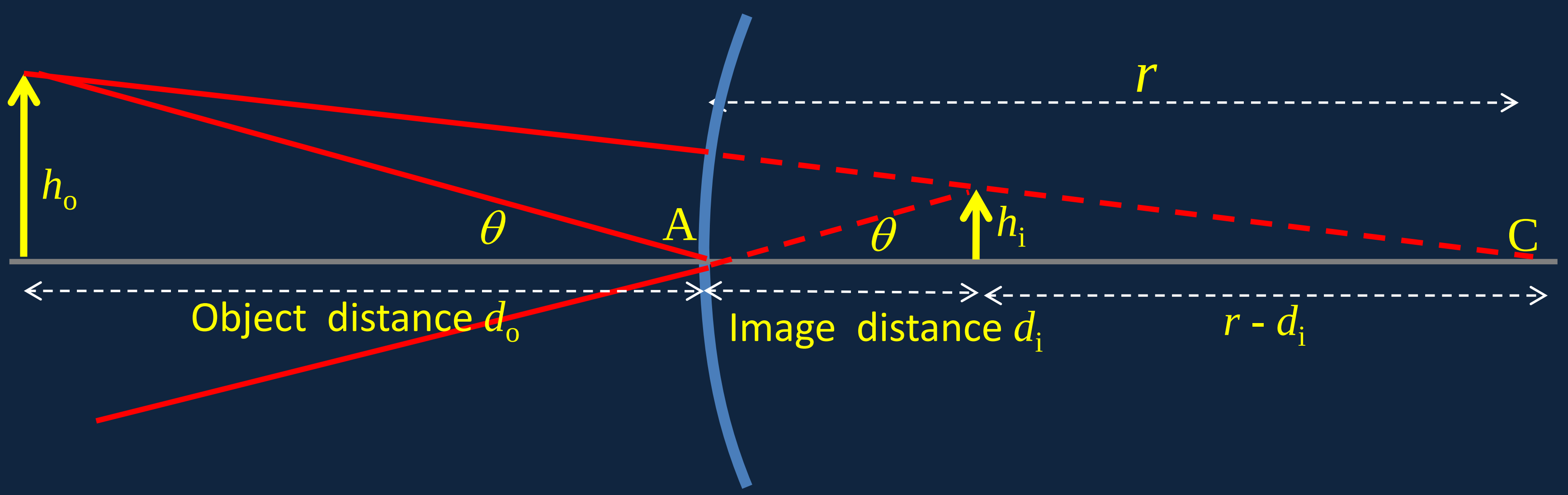
- Dividing both sides bu $d_o d_i r$ gives $\frac{1}{d_o} + \frac{1}{d_i} = \frac{2}{r} = \frac{1}{f}$



Virtual Image for Convex Mirror

- A convex mirror never produces a real image, but the ray geometry is very similar to that above:

$$\frac{h_o}{h_i} = \frac{d_o}{d_i} = \frac{d_o + r}{r - d_i}, \quad d_o r - d_o d_i = d_o d_i + d_i r$$

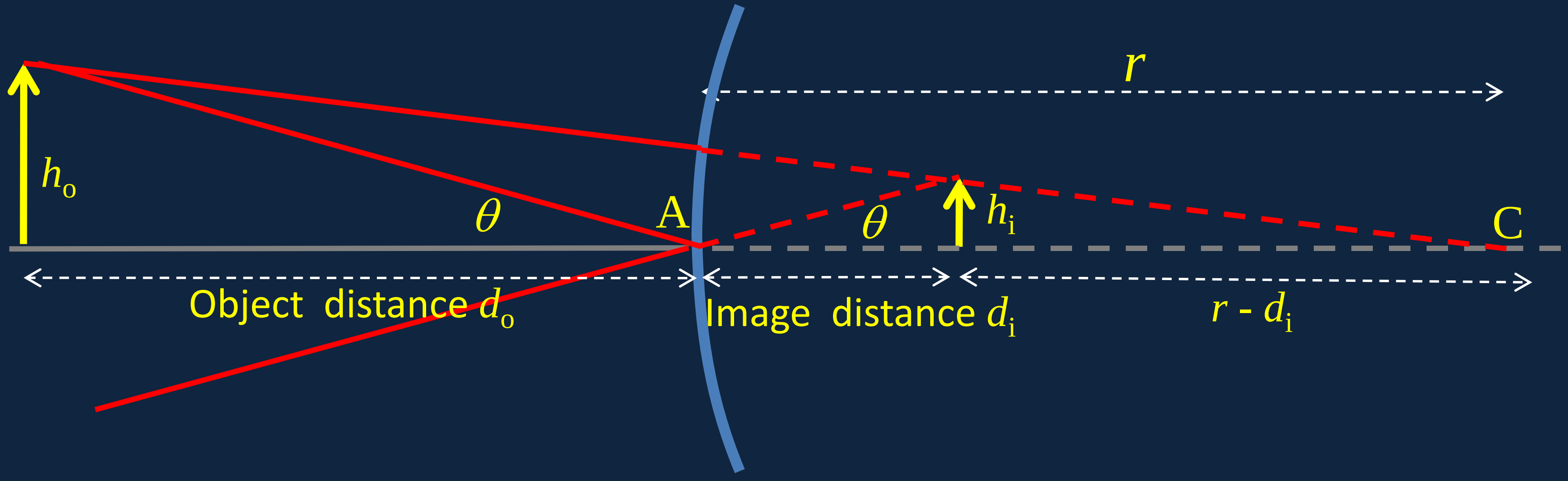


For a convex mirror, a virtual image is always smaller than the object.

Sign Convention for Convex Mirror!

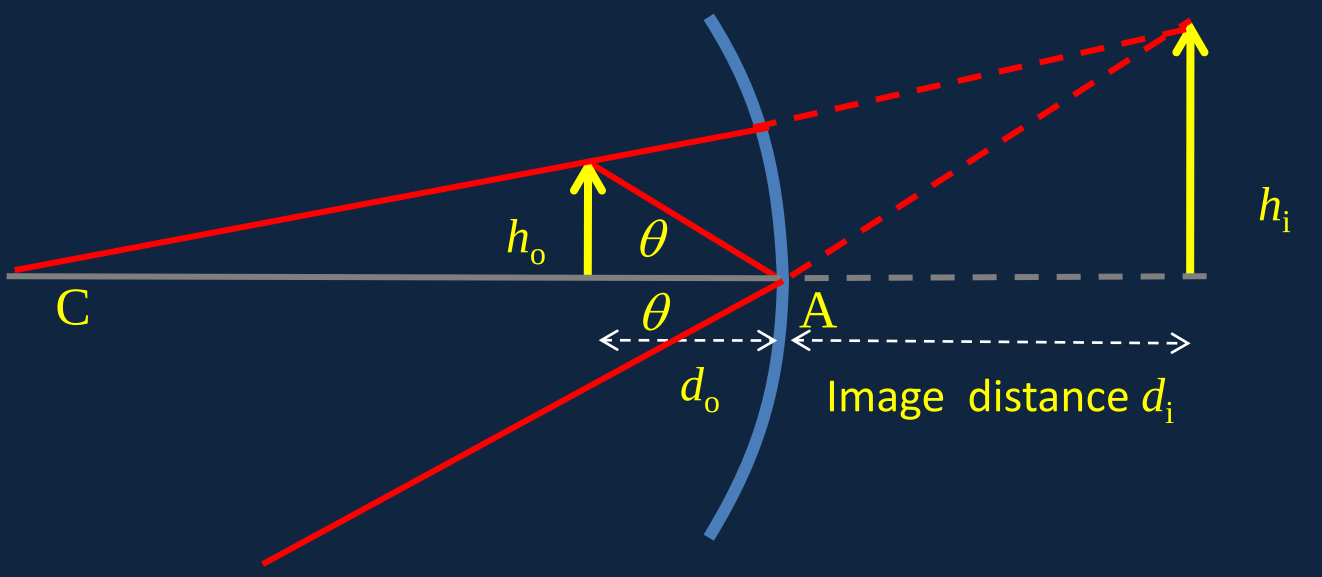
- Distances behind the mirror, including the radius of curvature and the focal distance, count as negative.
- Making the appropriate adjustments to the formula we just found gives the same formula as for the concave mirror:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{2}{r} = \frac{1}{f}$$



Virtual Image for Concave Mirror

- If an object is closer to a concave mirror than the focal length, the mirror will give a magnified virtual image. The magnification is defined as the size ratio, h_i/h_o.



Using the formula

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$$

for this case, d_o and f are positive, <u>d_i is negative</u>.

For a concave mirror, a virtual image is always bigger than the object.