Physics 1230: Light and Color

- REFLECTION
- Geometrical optics - how does light change direction?
  - Reflections (mirrors, seeing your image)

http://www.colorado.edu/physics/phys1230
Examples of Reflections

- RADAR
- SONAR
- Radio wave (AM) propagation
- Reflection from a mirror
- Reflection from glass
- Silvered sunglasses
- Periscopes
- Magic mirrors
- Two-way mirrors
- Sun pillars
Demonstrations and Simulations on Reflection

- Rope tied to a wall - hard reflection
- Rope tied to a string - soft reflection
- Full reflection - your image in a vanity mirror, reflection from a mirror
- Partial reflections - image in glass window, half-silvered mirror
- Colored reflections - gold mirrors, aluminum mirrors, silver mirrors
Geometrical optics - Reflections

- Light travels in straight lines until it reflects off something.

- Reflections of any kind of wave occur whenever the medium of propagation changes abruptly e.g. rope tied to a wall or a string.

- What counts is the change in the wave’s speed of propagation. If no speed change occurs, there is no reflection.

- If the speed changes dramatically, most of the wave is reflected. If there is little change in speed, little reflection occurs.
Applications of reflections - RAdio Detection And Ranging

• Radar is based on reflected or echoed electromagnetic waves of a billion hertz (or what wavelength?)

• If we know the speed of the wave, we can send out a pulse towards an object, and measure how long it takes for the reflection to return to us. Then - Distance = speed x time
Radio Detection And Ranging for Weather Forecasting

• Doppler radar is a type of weather radar that determines whether atmospheric motion is toward or away from the radar. It uses the Doppler effect to measure the velocity of particles suspended in the atmosphere.

• It employs the apparent shift in frequency of radio waves to perceive air motion and consequently predict tornadoes and precipitation sooner than previous radars, as well as measure the speed and direction of rain and
What is Imaging Radar?

An imaging radar works very like a flash camera in that it provides its own light to illuminate an area on the ground and take a snapshot picture, but at radio wavelengths. A flash camera sends out a pulse of light (the flash) and records on film the light that is reflected back at it through the camera lens. Instead of a camera lens and film, a radar uses an antenna and digital computer tapes to record its images. In a radar image, one can see only the light that was reflected back towards the radar antenna. The reflection depends both on shape and water content. Microwave wavelengths are in the range 1 cm to 1 m, which corresponds to a frequency range of about 300 MHz to 30 GHz.

(by Tony Freeman, Jet Propulsion Laboratory)
What is Imaging Radar?

A typical radar (RAdio Detection and Ranging) measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths (in the range 1 cm to 1 m, which corresponds to a frequency range of about 300 MHz to 30 GHz). For an imaging radar system, about 1500 high-power pulses per second are transmitted toward the target or imaging area, with each pulse having a pulse duration (pulse width) of typically 10-50 microseconds (us). At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some reflected back toward the antenna. This backscatter returns to the radar as a weaker radar echo. These echoes are converted to digital data and passed to a data recorder for later processing and display as an image. Given that the radar pulse travels at the speed of light, it is relatively straightforward to use the measured time for the roundtrip of a particular pulse to calculate the distance or range to the reflecting object.
Backscatter is also sensitive to the target's electrical properties, including water content. Wetter objects will appear bright, and drier targets will appear dark. The exception to this is a smooth body of water, which will act as a flat surface and reflect incoming pulses away from a target; these bodies will appear dark.
Sonar

• Bats use a system similar to radar - called sonar

• The waves bats emit are not electromagnetic waves but ultrasonic sound waves, at frequencies around 100 kHz (humans hear sound frequencies up to 20 kHz max)

• Sonar is also used to measure water depths, and to detect submarines
Sonar

ECHolocation
Bats send out sound waves using their mouth or nose. When the sound hits an object an echo comes back. The bat can identify an object by the sound of the echo. They can even tell the size, shape and texture of a tiny insect from its echo. Most bats use echolocation to navigate in the dark and find food.
Doppler Ultrasound in Medicine

Transducer (probe) on the abdomen

Doppler Ultrasound Images of Bloodflow in the Umbical Cord (above) & Heart (below)

Fetus at 9 weeks
Weather Radar is based on -

A) Reflection of radio waves by ice and moisture in the atmosphere?
B) Absorption of radio waves by ice and moisture in the atmosphere?
C) Reflection of sound waves by ice and moisture in the atmosphere?
D) Reflection of sound waves by bats?
Concept Question

Radar uses wavelengths in the range of

A) 300 km
B) 30 cm
C) 500 nm
Mirrors and Metals

How do mirrors work?

• Visible light propagates through transparent media - obviously!
• But visible light cannot propagate through metals. Why?
• Consider light propagation from air to glass, or air to water
• The EM field of the light causes the charges in the glass to oscillate
• These oscillating charges generate the reflected reflected (2-4%) and transmitted waves (96-98%)
• The light also slows down in the glass or air
Metals

- Metals have many free electrons that are not attached to individual atoms (this is why they are good conductors of electricity).
- These free electrons move under the action of the light wave to cancel out any field generated by the light (because they are free to move!)
- The oscillating free electrons generated an intense reflected wave, but no transmitted wave. Metal mirrors reflect 90-99% of the light.
Neil Armstrong with Gold-coated Visor on the Moon
Plasma Frequency

• What happens if the light frequency is too high? i.e. if the light wave oscillates too fast for the electrons to keep up?

• The free electrons can no longer reflect all the light, and the metal (or gas plasma) becomes somewhat transparent.

• The frequency at which this happens is called the PLASMA frequency.
### Plasma Frequencies of metals

<table>
<thead>
<tr>
<th>Metal</th>
<th>Plasma frequency</th>
<th>Color of metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>above visible</td>
<td>white - since reflects all colors</td>
</tr>
<tr>
<td>Gold</td>
<td>in the blue</td>
<td>yellow - since reflects red and green</td>
</tr>
<tr>
<td>Copper</td>
<td>in the blue-green</td>
<td>reddish - since transmits blue &amp; green</td>
</tr>
</tbody>
</table>
Concept question

Metals reflect all EM waves with frequencies—

A. higher than plasma frequency
B. lower than plasma frequency
C. all wavelengths
D. at the plasma frequency

Diagram showing the plasma frequency for copper, gold, and silver.
The Ionosphere

Earth’s atmosphere varies in density and composition as the altitude increases above the surface. The lowest part of the atmosphere is called the troposphere (the light blue shaded region in the figure to the left) and it extends from the surface up to about 10 km (6 miles). The gases in this region are predominantly molecular Oxygen (O2) and molecular Nitrogen (N2). All weather is confined to this lower region and it contains 90% of the Earth's atmosphere and 99% of the water vapor. The highest mountains are still within the troposphere and all of our normal day-to-day activities occur here. The high altitude jet stream is found near the tropopause at the upper end of this region.

The atmosphere above 10 km is called the stratosphere. The gas is still dense enough that hot air balloons can ascend to altitudes of 15 - 20 km and Helium balloons to nearly 35 km, but the air thins rapidly and the gas composition changes slightly as the altitude increases. Within the stratosphere, incoming solar radiation at wavelengths below 240 nm. is able to break up (or dissociate) molecular Oxygen (O2) into individual Oxygen atoms, each of which, in turn, may combine with an Oxygen molecule (O2), to form ozone, a molecule of Oxygen consisting of three Oxygen atoms (O3). This gas reaches a peak density of a few parts per million at an altitude of about 25 km (16 miles). The ozone layer is shown by the yellow shaded region in the figure to the left.

The gas becomes increasingly rarefied at higher altitudes. At heights of 80 km (50 miles), the gas is so thin that free electrons can exist for short periods of time before they are captured by a nearby positive ion. The existence of charged particles at this altitude and above, signals the beginning of the ionosphere a region having the properties of a gas and of a plasma. The ionosphere is indicated by the light green shading in the figure to the left.

Edward V. Appleton was awarded a Nobel Prize in 1947 for his confirmation in 1927 of the existence of the ionosphere.
Selected Frequencies

- Visible light frequency: \(10^{14}\) Hz
- Ionosphere plasma frequency: \(10^8\) Hz
- TV, FM: \(10^8\) Hz = 100 MHz
- AM radio: \(10^6\) Hz = 1000 kHz

Waves reflect from mirrors or the ionosphere if their frequency is less than the plasma frequency.
Waves reflect from mirrors or the ionosphere if their frequency is less than the plasma frequency.

Concept Question:
What radiation reflects off the ionosphere (plasma frequency $10^8$ Hz)
A. Visible light
B. Radar
C. AM radio
Skywave Propagation

Sky-wave propagation (SKIP) is the way radio waves bounce back and forth between the ionosphere and Earth. The ionosphere is the area 25 to 200 miles above the Earth which is electrically charged (ionized) by radiation from the Sun. When ionized by solar radiation, the ionosphere can refract radio waves back to Earth.

Since the Earth is round, radio waves cannot travel in a straight line. Therefore, they bounce back and forth between the ionosphere and Earth as they travel from the ham radio operator to their destination. Under good conditions, it makes three or four bounces before landing and worldwide communication is achieved. Under poor conditions it might only make one reflection and stay within the United States.

Ionization of the ionosphere occurs when the sun's radiation strikes the upper atmosphere. The amount of radiation changes during the course of the day, season, and year. Ham radio operators can determine how much the ionosphere will refract radio waves by where the sun is in its sunspot cycle. Sunspots are dark blotches on the sun's surface and their numbers and sizes change over an 11-year period. More sunspots generally means more ionization of the ionosphere, and therefore, greater distance when sending a message by radio waves.

**FIGURE 2.15**

Reflection of radio signals from the ionosphere makes distant reception possible. The ionosphere rises at night, increasing the range of reception. (Exaggerated for clarity.)
LAW OF REFLECTION

- Angle of Incidence = Angle of Reflection
- You know this intuitively
- This law is true for both flat and structured surfaces

Applet on Law of Reflection

Specular reflections

BOTH obey the Law of Reflection!

Diffuse reflections
BOTH obey the Law of Reflection!


Applet on Specular and Diffuse Reflection
Concept Question:
You are more likely to see a good image of yourself from -

A. Pool of water

B. Metal sheet

C. Window glass
BOTH obey the Law of Reflection!

Applet on Specular and Diffuse Reflection
Concept Question:
Does the law of reflection apply to -

A. Metal mirrors
B. Glass surfaces
C. Both
EXAMPLE OF REFLECTION - PERISCOpes

- Angle of Incidence = Angle of Reflection
FIGURE 23-6  A beam of light from a flashlight is shined on (a) white paper, and (b) a small mirror. In part (a), you can see the white light reflected at various points because of diffuse reflection. But in part (b), you see the reflected light only when your eye is placed correctly ($\theta_r = \theta_i$); this is known as specular reflection.
How do you see an image of yourself in a mirror?
How we see an image

**FIGURE 23-7** Formation of a virtual image by a plane mirror.
Mirror, Mirror on the Wall

• What do you notice about these reflections?
EXAMPLES OF REFLECTION - MAGIC MIRRORS

• Angle of Incidence = Angle of Reflection
EXAMPLES OF REFLECTION - 2-WAY MIRRORS

Can also see the effect of partial reflections from silvered sunglasses
EXAMPLES OF REFLECTION - SUN PILLARS

- Angle of Incidence = Angle of Reflection
- Here ripples on the surface of the water reflect the light into your eye. The ripples cause the reflections to appear to come from different points - and therefore causes the formation of an apparent sun pillar.
- What happens if the water surface is flat?
  A. See image of round sun
  B. See image of smooth sun pillar
Concept Questions on reflection – wet vs. dry road

• Is it easier to see ahead on a A) dry or B) wet road at night?

• For a dry road, the reflections of the car headlights are A) diffuse or B) specular

• Specular reflections make the road A) more or B) less visible for the driver
For a wet road, the reflection is more specular, making the road difficult to see.