Modern physics ideas are strange!

- Electromagnetic waves sometimes behave like particles—photons—discrete (quantized) packets of energy $E = hf = hc/\lambda$.
- Electrons sometimes behave as waves—matter waves—that can only exist in allowed orbits.
  - Electrons have a wavelength and can experience diffraction.

The Photon Concept

- A beam of light waves also behaves like a beam of light particles called photons.
- Photons are little packets of electro-magnetic energy.
- The energy is proportional to the frequency or inversely proportional to the wavelength:
  $E_{\text{photon}} = hf$, but $c = f\lambda$, so $E_{\text{photon}} = h c/\lambda$.
- Where $h$ is a constant called Planck's constant, and $c$ is the speed of light.
- Blue photons have more energy than red photons.
- Energy is absorbed or emitted in discreet amounts, e.g., sodium absorption line.

The uncertainty principle

- In classical physics we can measure the position and velocity of a particle simultaneously.
- At the atomic level, measurements can disturb what we are trying to measure.
- To locate an electron and measure its velocity, we have to scatter a photon from it, but this will change its velocity.
- We cannot measure $(x, v)$ precisely—uncertainty.

X-ray and gamma ray photons

- X-rays are very short wavelength photons.
- Gamma rays are even shorter wavelengths.

X-ray machines

- X-ray machines use X-rays and gamma rays to produce images.
- $E = hf = hc/\lambda$.
How are x-rays produced?

- When electrons that have been accelerated through about 50,000 volts slam into a piece of copper, some of the electron energy is converted to x-rays.
- X-rays are energetic enough to penetrate through soft tissue and thin metal foils.

Gamma rays

- Extremely energetic photons
- Constantly bombard the earth
- Cosmic rays
- Emitted by radioactive materials
- X-ray photons are a 1000 times more energetic than visible light photons
- Gamma ray photons are 1,000,000 more energetic than visible light photons

LASERS  A device that controls the way that energized atoms release photons.

- Light Amplification by Stimulated Emission of Radiation
- First we must understand the difference between incoherent and coherent radiation.
- Ordinary light sources (light bulbs, fluorescent lights, etc) produce incoherent light.
- Lasers produce coherent light → all atoms radiate in the same manner.

Spontaneous vs Stimulated Emission

- Coherent radiation is produced when an atom undergoes stimulated emission.
- Spontaneous emission occurs when an electron makes an unprovoked transition to a lower energy level.
- Stimulated emission occurs when an incoming photon induces the electron to change energy levels → amplification.

A Helium-Neon (HeNe) Laser

Medical Applications of Lasers

- Laser surgery to correct for (a) nearsightedness, and (b) farsightedness.
Applications of High Power Lasers

- Using lasers to cut metals
- Laser weapons to protect ships from missile attacks

Laser Fusion Energy

- Multiple beams of a powerful laser are focused on a tiny pellet containing fusion fuel
- The laser energy compresses the pellet producing a mini-hydrogen bomb that produces energy

Solid State Laser Diodes

- Come in a variety of different colors

Lasers Diodes

- Diode lasers use semiconductor materials (tiny chips of silicon) as the lasing media
- When current flows through the silicon chip it emits an intense beam of coherent light.
- Diode lasers are used to read the information embedded in the pits in CD’s and DVD’s, and also to read UPC’s in bar code scanners and in laser pointers!

How does a CD burner Work?

- infrared laser light is applied to a layer of photosensitive dye on top of the plastic
- this causes the dye to darken (no burning!)
- by selectively darkening particular points along the CD track, and leaving other areas of dye translucent, a digital pattern is created that can be read by a standard CD player
Medical Imaging Techniques

- x-rays
- CT and CAT scans (Computerized Tomography)
- MRI’s (Magnetic Resonance Imaging)

X-rays

- very short wavelength (0.01 – 0.1 nm) electromagnetic waves
- produced when energetic electrons slam into a metal target
- able to penetrate soft tissue, but not bone
- produces a two dimensional shadow image

A pineapple and a banana

- A shadow image can be misleading
- two shadows taken from different angles provides a better picture
- shadows taken at multiple angles gives a more complete picture
- this is what a CT or CAT scan does

CAT Scans

X ray images are taken at many different angles passing through the patient. Some of the cuts overlap. A full three dimensional image can be reconstructed using computers. this procedure is called tomography.

Computerized Tomography

- A computerized tomography or CT scan image is formed by analyzing x-ray shadow images taken at many different angles and positions
- an x-ray source and an array of electronic detectors rotates around the patient as the patient slowly moves through the ring.

Is there a better medical diagnostic?

- A CAT scan does a good job of imaging bones, but it does not provide as good an image of soft tissue
- Also, it requires that the patient receives a big dose of x-rays, which can be harmful in themselves → it is an invasive diagnostic
- Magnetic resonance imaging (MRI) is a better method of imaging soft tissue
MRI Device

MRI finds the hydrogen atoms

- MRI works by locating the hydrogen atoms inside the body. Since the body is mostly water, there are lots of hydrogen atoms.
- The nucleus of a hydrogen atom is a single proton. Protons behave like tiny bar magnets with a north pole at one end and a south pole at the other end.
- If you put a bar magnet in a magnetic field, it will try to align itself with the field.

A bar magnet in a magnetic field

MRI – How it works

- Unlike CT, MRI uses no ionizing radiation, but uses a powerful magnetic field to align the nuclear magnetization of (usually) hydrogen atoms in water in the body.
- Radio frequency (RF) fields are used to systematically alter the alignment of this magnetization, causing the hydrogen nuclei to produce a rotating magnetic field detectable by the scanner.
- This signal can be manipulated by additional magnetic fields to build up enough information to allow computers to construct an image of the body.

CT Scan vs. MRI

<table>
<thead>
<tr>
<th></th>
<th>CT Scan</th>
<th>MRI</th>
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<tbody>
<tr>
<td>Cost</td>
<td>$1200 - 3200</td>
<td>$1200 - 4000</td>
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<tr>
<td>Details of bone structures</td>
<td>Provides good details about bony structures</td>
<td>Less detailed than CT</td>
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<tr>
<td>Change image plane w/o moving the patient</td>
<td>no</td>
<td>yes</td>
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<tr>
<td>Radiation exposure</td>
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<tr>
<td>Time</td>
<td>5 minutes</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Details of soft tissue</td>
<td>Less detail than MRI</td>
<td>Much higher detail</td>
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