Microcosmos

Quantum Mechanical Phenomena
Within the Nucleus
Nuclear physics
Cosmic rays
Particle physics
      Quarks, neutrinos
      Superstrings
      unification
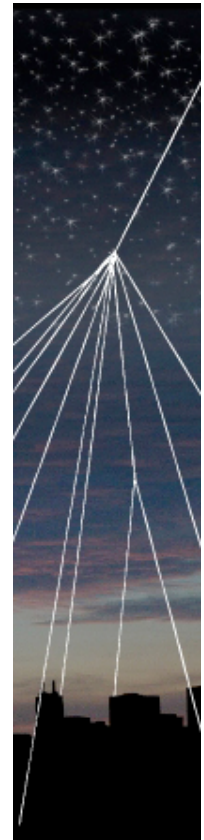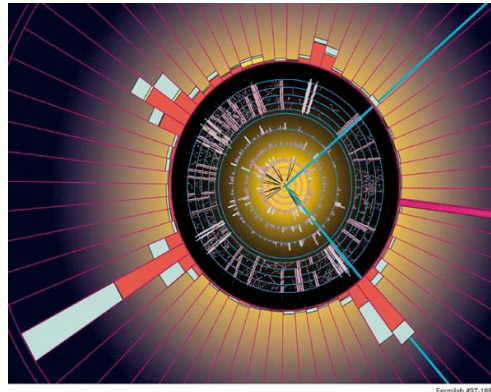
Macrocosmos

Relativity
      Special relativity
      General relativity

Gravity's Domain
      Black hole formation
      Big Bang Cosmology

Hubble Deep Field   HST · WFPC2
PRC96-01a · ST ScI OPO · January 15, 1996 · R. Williams (ST ScI), NASA
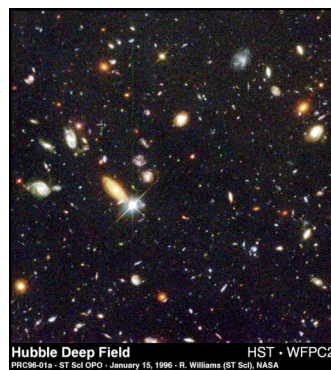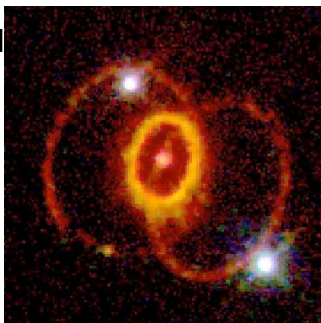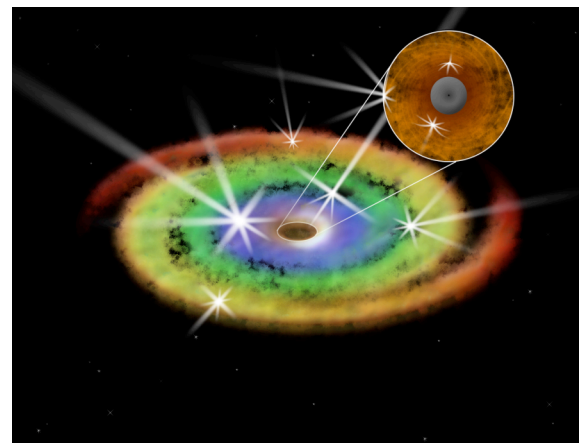
The Frontier

Superstrings
Extra dimensions

Dark matter

Dark energy

What we can see visually is extremely restructed:

    – Human attention to nature's order
        – languages form basics (states of matter)
            – hard:soft, wet:fluid, air:breath
            – bright:dark — relative presence of radiation
            – fast:strong — dynamics, motion, force
            – verb tenses, precedence — notions of time
            – up, down, right, left - four cardinal points — spatial
                notions

Cultural focus appears to vary:

    – forces of nature
        – Zulu (amandala)
        – Yoruba
        – call this 'Interaction'
    – structure of time and space
        – Maya
        – Lakota
        – Hopi
        – call this 'Dimension'
    – building blocks of matter
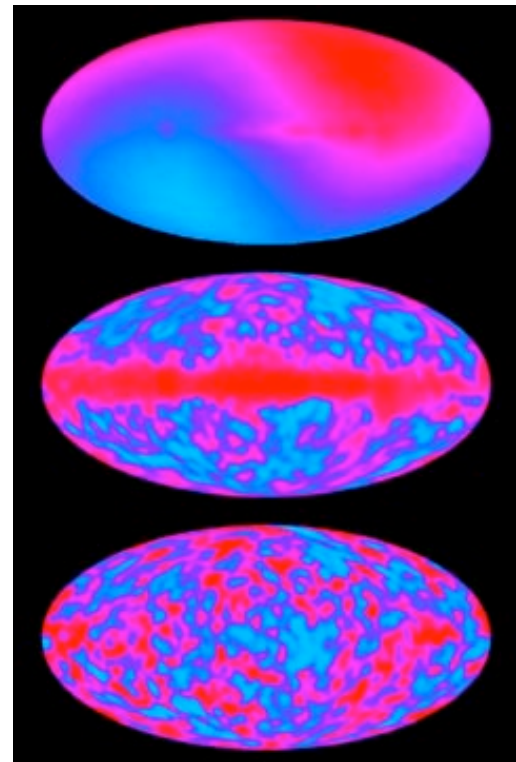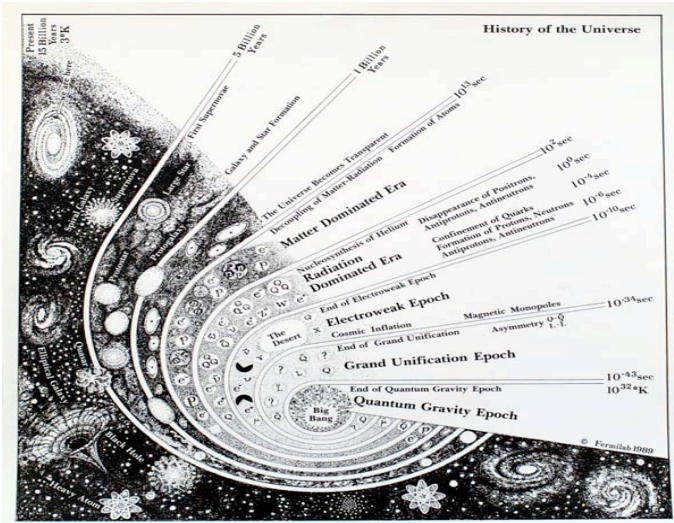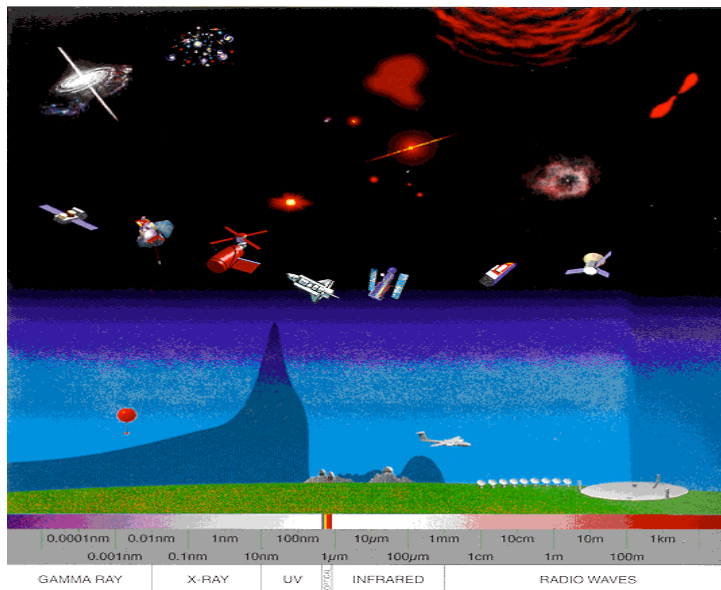   – Greece (atomism)
        – India (vaisesika atomism)
        – China
        – call this 'Particles'

    – the attention to these three primary categories of Nature
        (Interactions, Dimensions and Particles) is at the heart of the
        study of Physics

Natural Science, or Natural Philosophy   L1p2

physiké epistémé: Gr. the knowledge of nature; **physis** = nature (cognate
    with L. **nasci** = to be born, source of word 'Nature'); **phyein** = to
    produce, to bring forth, beget, grow, to plant

    physis is not about growth of quantity alone
        – what opened up before them is called '**physis**', so this means
            the sky and the earth; stone and plans, animals, people,
            the work of people and gods.
        – the universal 'breeding ground'

Very broad field of thought: it is this broadness that tends to make
physics the science exploring underlying mechanisms in Nature
    – Biophysics, Condensed Matter, Atomic/Molecular/Optical,
        Astrophysics, Cosmology, Particle Physics...
It turns out that there is alot going on in nature that we can't see, i.e.
it has 'physics'.

Where and When is Event?

When?   (time)

- when does an event happen?
    - o   does it tend to happen early or late?
- when does it occur in relation to other events?
    - o   are the events simultaneous?
    - o   which one precedes the other?

Where?   (place)

- where does it happen?
    - o   'is it local, or far away?
- is what environment does it occur?
    - o   is there a lot of other stuff around it?
    - o   what kinds of things tend to happen in such an environment?

Mathematics

Babylonians, base 60 arithmetic gives us our measure of time

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Greek Geometry
        - considered a higher math than working with numbers
        - One axiom: parallel lines never intersect

Arab Algebra
        - the unknown element and its determination
        - numerical approaches to solving and quantifying
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- Slopes and curves --> trends, but instantaneous moments difficult

■*Motion and matter*

Essentially atomistic view: i.e. tiny indestructible particles comprise material with identity

Celestial and terrestrial worlds separate

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Terrestrial phenomena
        - changeful (weather)
        - imperfect

Celestial phenomena
        - stars constant motion thru the year
        - planets and Moon: more erratic but predictable motion
        - perfect, unchanging
        - heliocentric and geocentric models of motion
            - both Greece and India had both views
            - embedded in mystical or religious beliefs

Motion
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- Apparent stellar and planetary motions, plus falling objects
- provide idea of a 'true point' to be center of the Earth
- Only circular paths (or combinations thereof) are considered
```
        - objects fundamentally resist motion
```
- Action of other bodies causes displacement

Lecture 2: Classical Picture

Galileo – the first Physicist (perhaps the first Scientist)
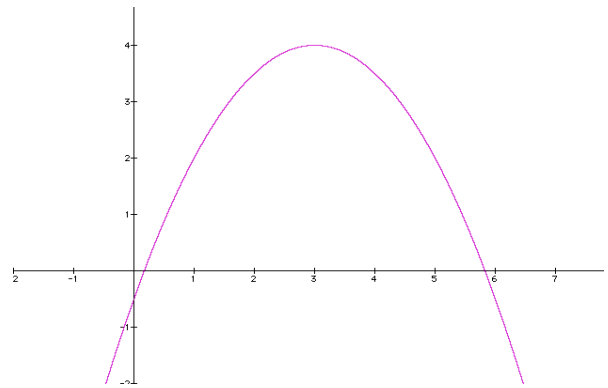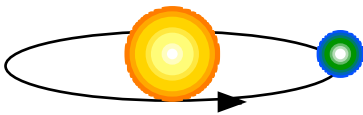
experimental science
- must verify ideas with tests by measurement & observation
- physical phenomena should adhere to logic of math

mathematical science
- laws of nature written in language of mathematics

swept aside key ideas
- natural state not "no motion"
- applied action produces change in motion, not just position
- geocentrism not correct (phases of Venus)

View of Matter
- basically atomistic
  - infinitesimal particles like hard pellets: precise positions & motion

Motion
velocity is change in position for a given period of time: $\Delta x/\Delta t$
- velocity has a magnitude (eg. 60 mph) and a direction (eg. northwest)

"change in motion" = change in velocity, v
- rate of change of velocity $\Delta v/\Delta t = a$ (acceleration)

Law of Inertia: any object will remain at rest, or in a constant velocity, unless acted upon

Newton's laws of Motion

1) An object will remain at constant velocity unless acted on by a "force"
- a force can be applied either directly (e.g. N, collision) or at a distance (e.g. gravity)

2) For every action, there is an equal and opposite reaction

3) $\boxed{F=ma}$, where "m" is the object mass and "a" is its change in velocity, (its acceleration)
- m here is the 'inertial' mass a measure of haw hard it is to move the object

Conservation of Energy & Momentum

- Energy of motion ('kinetic energy'), $E_{kin} = (mv^2)/2$
    - The total energy of a closed system cannot change

- momentum, $p = mv$
    - The net momentum of a closed system cannot change when 2 particles collide in same way (i.e. velocities, angles)

deterministic mechanics:
- the cosmos is a clockwork
    - once the hands of the clock are set
    - evolution of the system completely determined
- outgoing velocities completely predetermined and one can know positions & velocities infinitely well.
- when 2 particles collide elastically each particle has energy by virtue of its motion and "momentum"
- Energy & momentum (a measure of velocity*mass) precise terms describing state of action of a particle

Gravitation

unification of celestial and terrestrial physics or motion
    - hypothesized to be result of same force, gravity

$$F = G \, m_1 \, m_2 / r^2$$

- o m1 and m2 are "gravitational masses"
- o G chosen so inertial & gravitational masses same
    - ▪ why is this possible?

Mechanics:

The starting point for mechanics is the concept of *inertia*, a property of matter described in the Law of Inertia from Galileo. This states that an object will continue with a constant velocity until acted upon by a force. Such a force will produce an *acceleration* (i.e. F=ma). Acceleration is a change per unit time in either the magnitude of velocity, its direction, or both.

Given the concept of inertia, we find it useful to talk about 'inertial reference frames' which are three-dimensional coordinate systems which travel at constant velocity. To determine the coordinates of an event in one frame, say S, when we know it's coordinates in another frame, say S', we employ the Galilean space and time transformations.
If we have an object in frame S' moving with velocity, v, within that frame, and S' is moving with velocity V' relative to frame S, then the velocity of the object in the frame S is equal to v+V'. This is the Galilean velocity transformation. The Principle of Galilean Relativity states that the laws of mechanics are the same in all inertial reference frames.

Another pair of concepts which are important to discussing mechanics are *momentum* and *energy*. These two related properties of matter have larger values when there is an increase in either the mass of an object or its velocity. The specific manner of the dependence is different in the two cases, with momentum preserving knowledge of the direction of an object (or group of objects) while energy does not. In all situations, the total momentum and total energy of a group (or 'system') of objects is constant. Classically, energy may not be created from nothing or destroyed to nothing.

Lastly, the gravitational force between two objects with masses 'm' and 'M' is calculated classically as $F = -G (mM)/r^2$. The mass that enters here is termed the 'gravitational mass'. The mass which enters the generic force equation above (F=ma) is termed the 'inertial mass'. These two turn out to be the same and this is unexplained in classical physics.

Electromagnetism

- electricity:
    - lightning, electric current, shock
    - a force like gravity (sort of) $1/r2$
    - electrial charges govern strength
- magnetism
    - compass needle
    - a force very different from gravity: eg. no magnetic monopoles?
    - it was shown that electrical current produces magnetism

- **Maxwell's Equations**
    - unify the descriptions of electricity & magnetism
    - predict speed of light 3×108 m/s
        - light is what "carries" the electromagnetic force
        - What does light travel in?
        - what is speed of light with respect to?
    - oscillating charged particles generate electromagnetic waves   light

    – electromagnetism only force apparent at micro and macro levels

Waves:

Examples: water waves, sound waves

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a wave:
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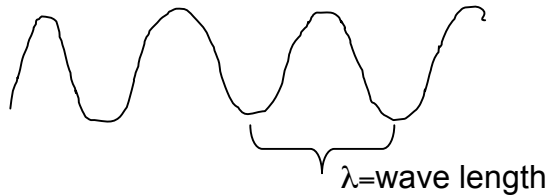

λ=wave length

wave motion
> velocity, $v = \lambda f$, where v is velocity of wave and lambda and f are wavelength and frequency,
>> respectively
>
> for a given kind of wave, the velocity is fixed (eg. sound waves have same velocity in air, regardless of
>> pitch or frequency)
>
> big λ corresponds to small frequency, f, (and vice versa) for a given velocity
>> o   lower λ, higher frequency

guitar string
> - if hold down finger
>> - string only vibrates with wavelengths (of sound) that fit into string length, l
>>> - (i.e. wavelength = l, l/2, l/3, l/4, etc.)
>>> - harmonic, wavelength = l solely present
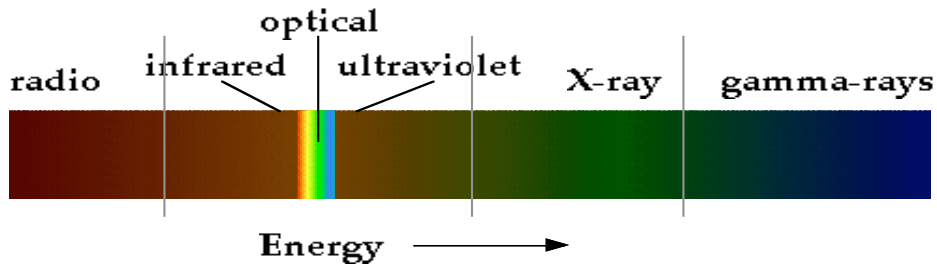>
> string, frequency is pitch you hear
>> o   for sound, long wavelengh = Bass, short wavelength = Soprano
>>> - spectrum: Bass, Baritone, Tenor, Alto, Soprano

water waves
> - frequency is rate at which peaks pass by

electromagnetic waves

- white light is composite: made of range of red to blue light
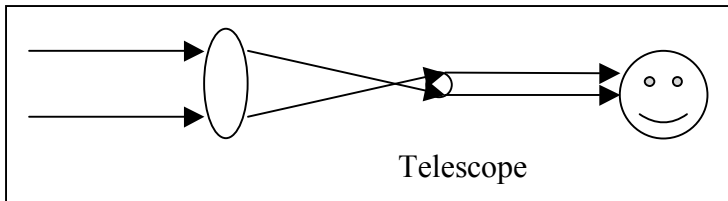- red has longer wavelength (lower energy) than blue light

- a clue to temperature
    - a heated body radiates light in range of wavelengths
   - the typical wavelength is smaller (bluer) for hotter objects

Lecture 3: Problems with Light I
Waves vs. Particles

- Newton says they're particles
   o geometric optics

    o corpuscular theory
        ▪ travel in straight lines
        ▪ particles interact with material (glass) in lenses and this bends
          their path in a reproducible way

- Huygens says they're waves
    - when a wave intersects with a material that has a different composition
        - if that material is transparent, wave crests may change their
          spacing
        - if the wave does not hit this interface head-on
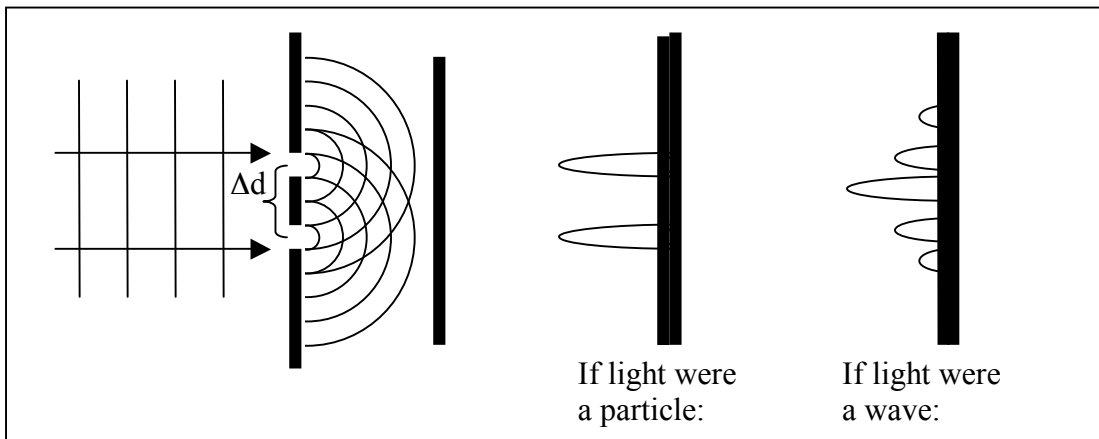   - direction of wave will change
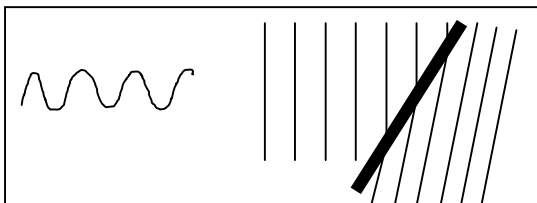
Double Slit Experiment

Imagine a light is incident on a opaque sheet with two slits in it. Behind this double slit is a screen.
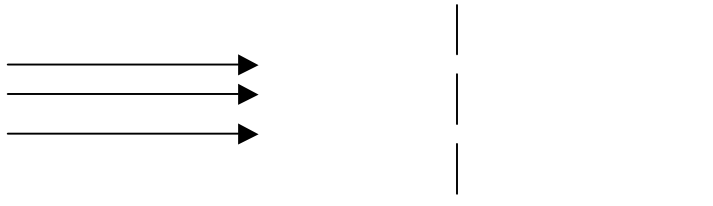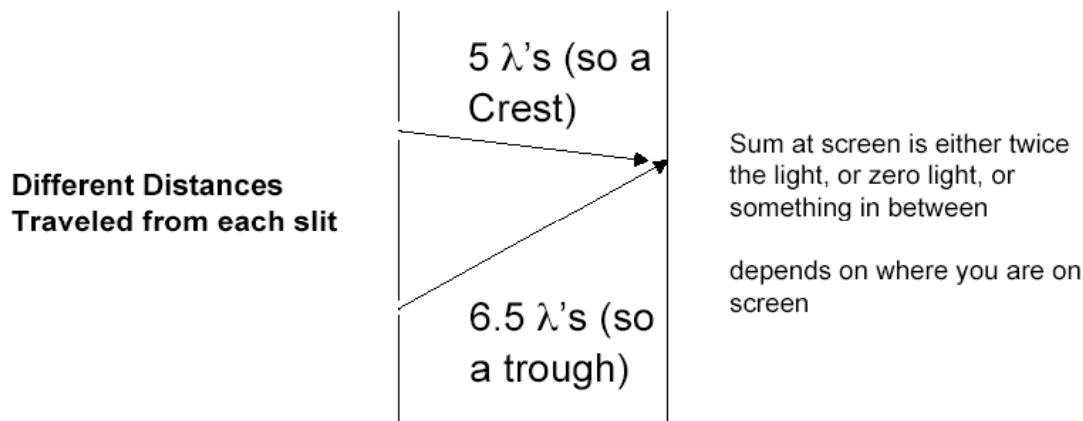
The question is, what will be the illumination pattern on the screen. The wave description of light would look like the following:

If light were
a particle:

If light were
a wave:

- If light is a particle it goes straight through it's slit & lights the screen.

- If light is a wave and inter-slit spacing ~ λ
    o waves emanate from each slit
    o if Δd=d1-d2=λ (is one wave length), then peaks & troughs add
    o if Δd=d1-d2=½λ (is half of a wave length), then peaks & troughs cancel.
    o
(This adding or canceling in Called Interference)

5 λ's (so a
Crest)

Different Distances
Traveled from each slit

Sum at screen is either twice
the light, or zero light, or
something in between

depends on where you are on
screen

6.5 λ's (so
a trough)

Electromagnetism and Light:

Electricity consists of the range of physical phenomena which result from the presence of electric charge. Magnetism consists of phenomena which result from the motion of charge. The fields of electricity and magnetism are unified by Maxwell's equations. These equations describe a wave associated with these forces which is called an 'electromagnetic wave'. This wave is predicted to have the speed of 300,000 km/s, which is the same as the measured speed of light. In classical physics, waves were commonly viewed as requiring a medium to travel thru or in. Since Maxwell's equations did not provide the speed of light with respect to any reference frame, it was conjectured that a pervading 'ether' existed throughout the universe in which the light could travel. It was thought that the speed of light was with respect to this absolute reference frame.

Light itself had been determined to have wave properties, particularly as evidenced by the Double Slit Experiment. In this experiment, a source of light is shined simultaneously thru two narrow slits onto a screen. If one of the slits is covered up, then the pattern observed on the screen is just the illumination of one slit. If both slits are uncovered, however, the light passing thru the two slits interferes. This interference produces a pattern of several alternating bright and dark lines on the screen and is incompatible with a particle nature of light.

It is important to understand the nature of waves, i.e. that they have a wavelength which is the peak to peak distance. They also have a frequency, which is the number of times per second that a peak will pass a given location when a wave is moving. When frequency increases, wavelength decreases. For visible light, or electromagnetic waves, high frequency corresponds to blue light and low frequency corresponds to red light. The visible spectrum encompasses the full range of colors between these extremes. The full light spectrum goes beyond this to include radio, infrared, visible, ultraviolet, X-ray and gamma-ray frequencies if we go from low frequencies to high frequencies.

Questions:

1) State the Principle of Galilean Relativity [4 pts]

2) Light is a gravitational wave.   (T or F)   [2 pts]

3) Electric current produces a gravitational force. (T or F) [2 pts]

4) Describe the concept of 'determinism' as it relates to classical physics. [4 pts]

5) State the Law of Inertia. [10 pts]

6) Light of short wavelength corresponds to [2 pts]

  a) high temperature
  b) low temperature
  c) large frequency
  d) a & c