PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 42200
Waves & Oscillations

Spring 2013 Semester

Matthew Jones

Preliminary Information

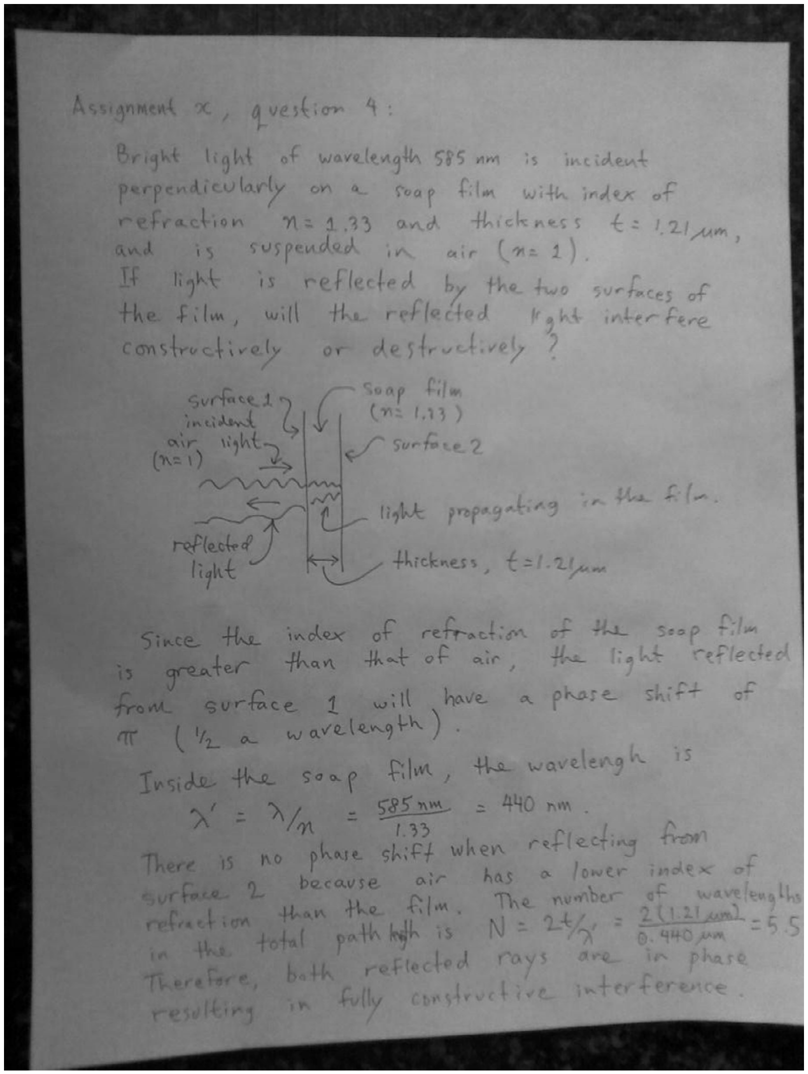
- Course web page:
  http://www.physics.purdue.edu/~mjones/phys42200_Spring2013
- Contact information:
  - E-mail: mjones@physics.purdue.edu
  - Office: PHYS 378
  - Phone: 765-496-2464
  - Office hours: Tuesday/Thursday 2 pm-3 pm or by appointment
- Textbooks:
  - A. P. French, Vibrations and Waves (required)
  - E. Hecht, Optics – 4th Edition (highly recommended)
- Lecture:
  - Not guaranteed to cover *all* the material you are responsible for on the homework or exams.
  - *May* cover material you are not responsible for but which will benefit your general education on the subject matter.
  - Read the text first, ask questions in class.

Preliminary Information

- Grading policy:
  - 30% homework
  - 30% midterm evening exam
  - 40% comprehensive final exam
- Homework policy:
  - Assigned on Friday, due the following Friday.
  - At most, one assignment will be dropped when computing final homework grade
    - Corollary #1: You can freely skip one assignment at your discretion
    - Corollary #2: No late homework will be accepted

Homework solutions must include complete, legible explanations of your work. It must be easy for the reader to follow your reasoning. If it takes longer for the grader to figure out your reasoning than it took you to write out your solution then something is wrong!

Assignments



Good!

BAD!

(But I've seen worse)

Assignments

- General advice:
  - In general, we don't care if you can get the right answer or not. You need to explain *why* it is correct.
  - Explain using words and algebra you arrive at a solution. Then substitute in numerical data, if applicable.
  - The algebra should be readable as part of a good English sentence: state what idea or information the formula is used to describe.
  - Symbols that are used without definitions or explanations are usually meaningless.
  - Diagrams can be extremely helpful. Make them large enough to convey the information they need to communicate.
  - Explain your logic! A bunch of formulas are not sufficient to explain the solution.
  - Re-iterate principles learned in class.
  - Your solution should read like an example found in a good text book.
  - Your solution should be useful for studying or reference long after it has been graded.

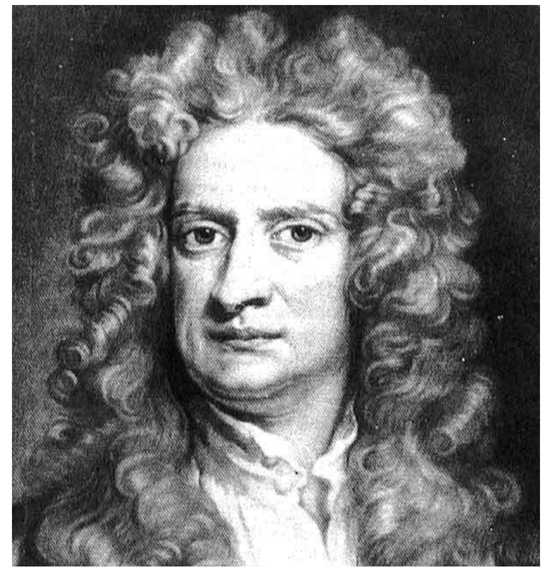
Oscillations and Waves

- Why study oscillations and waves?
  - A large fraction of all physical situations involve periodic or oscillatory behavior
    - Motion of the planets
    - Stable mechanical systems
    - Electrical systems
    - Fundamental forces
  - Periodic motion in continuous media
    - Wave propagation
    - Electromagnetic radiation (light/optics)
    - Quantum mechanics
  - Most fundamental description of nature
    - Quantum Mechanics + Special Relativity → Quantum Field Theory
    - Matter particles are quantized "waves" in an underlying "field".

Early Studies of Oscillations

Robert Hooke
(1635-1703)

Christian Huygens
(1623-1697)



Isaac Newton
(1642-1727)

$$F(x) = -k\,x$$

Oscillating Systems

- Differential equation:

$$m\frac{d^2x}{dt^2} + kx = 0$$

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

- Solutions:

$$x(t) = \boldsymbol{A}\,\cos(\omega t + \boldsymbol{\varphi})$$

$$x(t) = \boldsymbol{A}\sin\omega t + \boldsymbol{B}\,\cos\omega t$$

- The solutions are periodic with frequency

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{k/m}$$

Oscillating Systems

- Potential Energy:

$$F(x) = -\frac{dV}{dx}$$

- Linear spring described by Hooke's Law:

$$V(x) = \frac{1}{2}k\,x^2$$

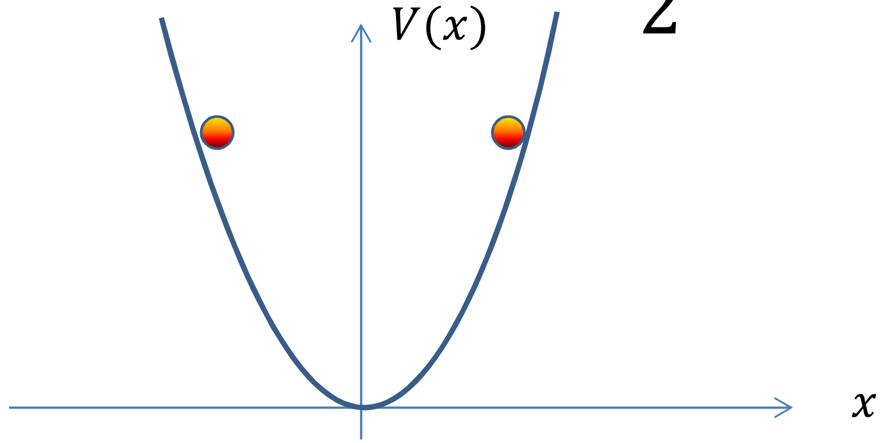
- Energy conservation:

$$E = T + V = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}kx^2 = const.$$

Visualizing Potential Energy

- Gravitational potential:

$$V(x) = mg\,h(x) = \frac{1}{2}k\,x^2$$



- When the force depends on position, the motion will be like that of a marble rolling on a suitably shaped surface.

Other Dynamical Variables

- The position, x, is used to describe the "state" of the system:
  - If you know x and $\dot{x}$ at one time, then you can predict what they will be at any other time.
- Other systems can be described using other dynamical variables:
  - Angles for rotating mechanical systems
  - Voltage or current in electrical systems
  - Electric or magnetic fields (*eg*, light!)

Other Oscillating Systems

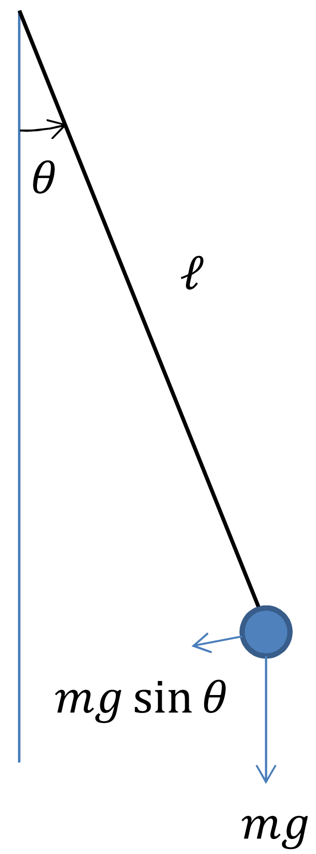
- A pendulum:

$$m\ell\ddot{\theta} = -mg\sin\theta \approx -mg\theta$$

$$\boxed{\ddot{\theta} + \omega^2\theta = 0,}$$

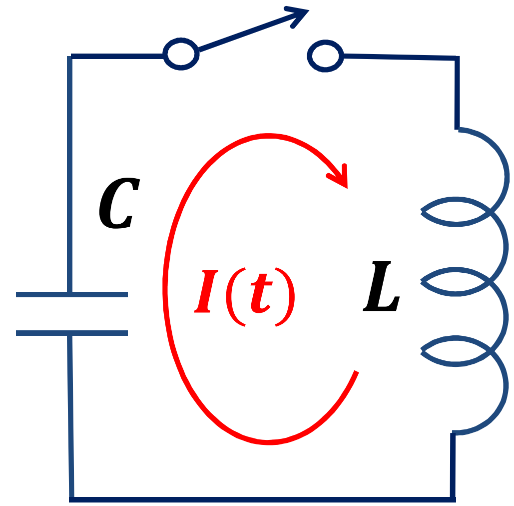
$$\omega = \sqrt{g/\ell}$$

$$\theta(t) = \boldsymbol{A}\cos(\omega t + \boldsymbol{\varphi})$$



Other Oscillating Systems

- An electric circuit:



$$\frac{1}{C}I + L\,\frac{d^2I}{dt^2} = 0$$

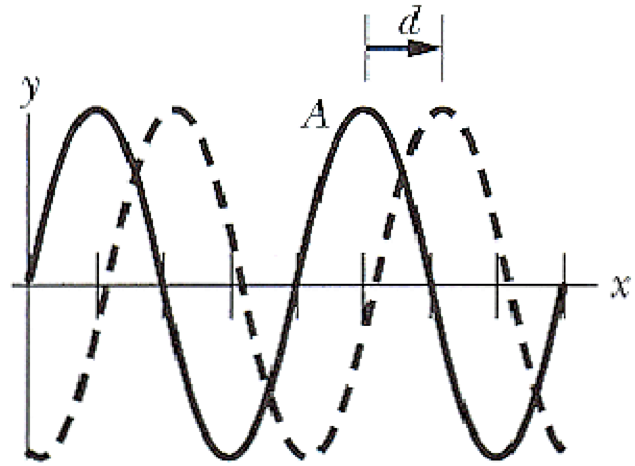
$$\boxed{\ddot{I} + \omega^2 I = 0,}$$

$$\omega = \sqrt{1/LC}$$

$$I(t) = \boldsymbol{A}\cos(\omega t + \boldsymbol{\varphi})$$

Other Oscillating Systems

- Waves:
  - Amplitude is a function of both x and t



- Wave equation:

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

- Solutions are of the form

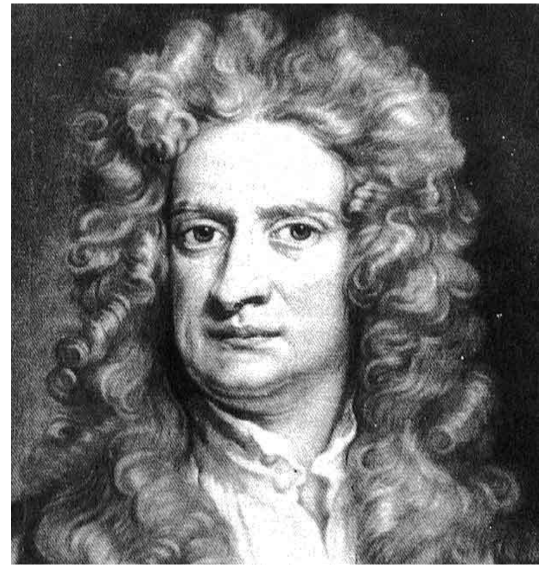
$$y(x,t) = \boldsymbol{A}\cos(kx - \omega t + \boldsymbol{\varphi})$$

Is light a wave?

Descriptions of Light

Christian Huygens
(1623-1697)

Promoted the “wave theory” of light.

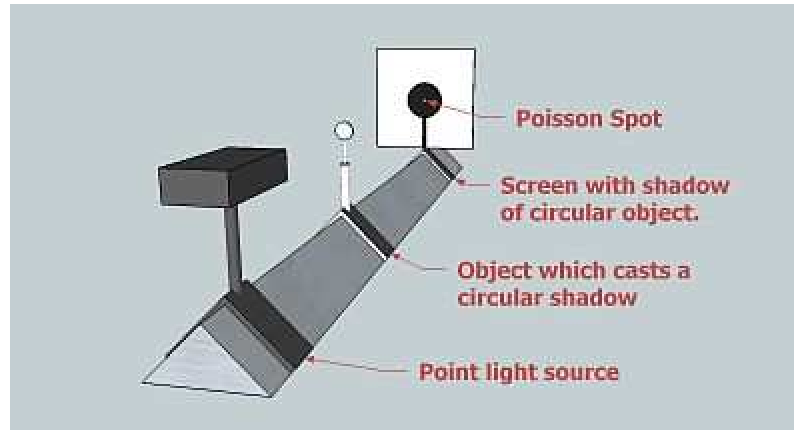


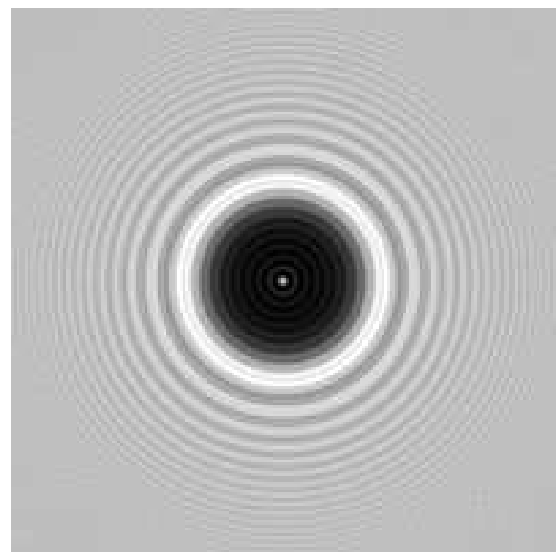
Isaac Newton
(1642-1727)

Described light as particles that moved in straight lines.

Diffraction Experiments

- Newton rejected the wave theory for good reason, but assumed the waves would be *longitudinal* like sound.
- A century later it was postulated that light could be a *transverse* wave.
- Based on the wave theory, Poisson, Arago and Fresnel predicted that there should be a bright spot at the center of a circular shadow.





Electromagnetic Radiation

By 1864, Maxwell had introduced four equations that described all known electromagnetic phenomena.

$$\oint_C \vec{E} \cdot d\vec{\ell} = -\frac{d\phi_m}{dt}$$

$$\oint_C \vec{B} \cdot d\vec{\ell} = \mu_0 \varepsilon_0 \frac{d\phi_e}{dt}$$

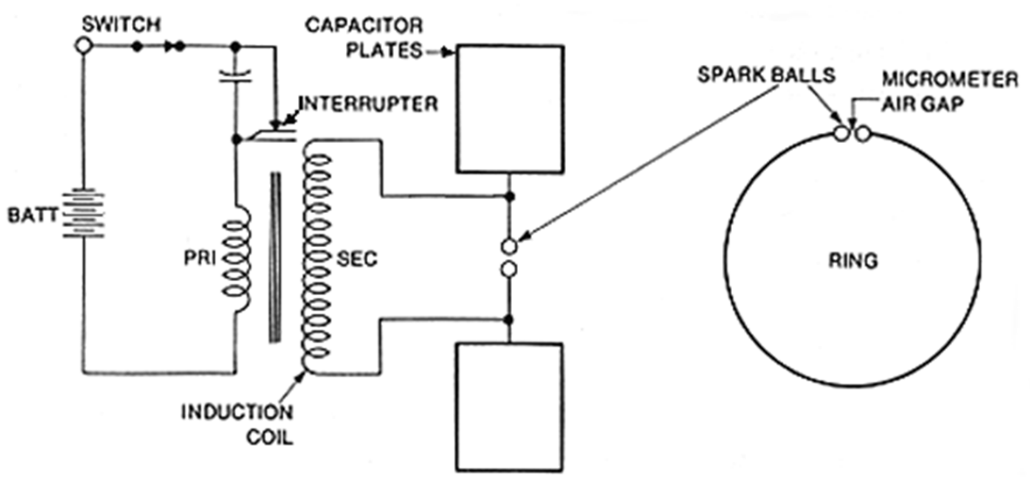
"An changing electric field induces a magnetic field and a changing magnetic field induces an electric field…"

$$\frac{\partial^2 E_x}{\partial z^2} = \mu_0 \epsilon_0 \frac{\partial^2 E_x}{\partial t^2}$$

$$v = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 2.998 \times 10^8\ m/s$$

Observation of Electromagnetic Radiation

Heinrich Hertz
(1857-1894)



"It's of no use whatsoever … this is just an experiment that proves Maestro Maxwell was right—we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there."

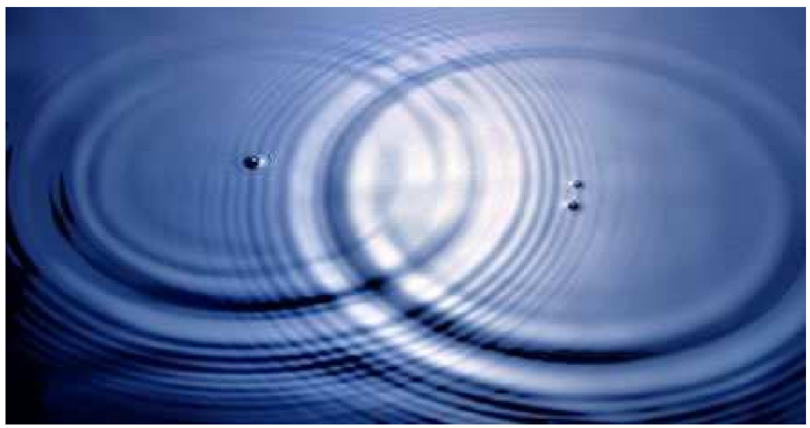
Asked about the ramifications of his discoveries, Hertz replied, "Nothing, I guess."

Modern Physics

- Maxwell's Equations could not explain:
  - Spectrum of light from blackbody radiation
  - Photoelectric effect
  - Speed of light is the same in all reference frames
- Quantum Mechanics:
  - Planck proposed that the energy of light was quantized, $E = h\nu$
  - Einstein explained the photoelectric effect: light was composed of particles with $E = h\nu$
  - Special theory of relativity: speed of light is the same in all reference frames.

Quantum Field Theory

- All particles are quantized excitations of a *field*.
  - Photons are quantized excitations of the electromagnetic field.
  - Electrons are quantized excitations of the "electron field".
  - Explains particle creation and annihilation.



- A natural mathematical consequence: the Higgs field.
- Very likely to have been directly observed last summer.
- But in this course we will only consider classical waves.