L 21 – Vibration and Sound [1]

- Resonance
- Tacoma Narrows Bridge Collapse
- clocks – pendulum
- springs
- harmonic motion
- mechanical waves
- sound waves
- musical instruments

Flow past an object

- object
- vorticies
- wind
- vortex street - exerts a periodic force on the object
- an example of resonance in mechanical systems

Vortex street behind Selkirk Island in the South Pacific

The earth is shaking

Earthquakes
http://www.geo.mtu.edu/UIP/Seis/waves.html
http://www.classzone.com/books/earth_science/terc/content/visualizations/es1005/es1005page01.cfm?chapter_no=visualization

Earthquakes and Tsunamis

- Normal situation
- Fault
- Earthquake generator
- Tsunami
- Coastal flooding
- Length candle burns

Keeping time ➔ Clocks

- hourglass
- sundial
- Length candle burns
- 1800 Clocks with mainspring
- Digital clock
length of a shadow

Clocks based on repetitive motion

- based on an object whose motion repeats itself at regular intervals
- pendulum clock
- first used by Galileo to measure time (Before this, Galileo, who was trained as a physician, used his own pulse as a clock.)
- based on harmonic oscillators – objects that vibrate back and forth

The pendulum - a closer look

- The pendulum is driven by gravity – the mass is falling from point A to point B then rises from B to C
- the tension in the string T provides the centripetal force to keep m moving in a circle
- one component of mg is along the circular arc – always pointing toward point B on either side. At point B this blue force vanishes.

The "restoring" force

- To start the pendulum, you displace it from point B to point A and let it go!
- point B is the equilibrium position of the pendulum
- on either side of B the blue force always act to bring (restore) the pendulum back to equilibrium, point B
- this is a "restoring" force

the role of the restoring force

- the restoring force is the key to understanding all systems that oscillate or repeat a motion over and over.
- the restoring force always points in the direction to bring the object back to equilibrium (for a pendulum at the bottom)
- from A to B the restoring force accelerates the pendulum down
- from B to C it slows the pendulum down so that at point C it can turn around

Repeating motions

- if there are no forces (friction or air resistance) to interfere with the motion, the motion repeats itself forever → it is a harmonic oscillator
- harmonic – repeats at the same intervals
- notice that at the very bottom of the pendulum’s swing (at B ) the restoring force is ZERO, so what keeps it going?
it’s the INERTIA!

• even though the restoring force is zero at the bottom of the pendulum swing, the ball is moving and since it has inertia it keeps moving to the left.
• as it moves from B to C, gravity slows it down (as it would any object that is moving up), until at C it momentarily comes to rest.

Energy in a pendulum

• to start the pendulum, we move it from B to A. At point A it has only gravitational potential energy (GPE) due to gravity
• from A to B, its GPE is converted to kinetic energy, which is maximum at B (its speed is maximum at B too)
• from B to C, it uses its kinetic energy to climb up the hill, converting its KE back to GPE
• at C it has just as much GPE as it did at A
• large pendulum demo

Some terminology

• the maximum displacement of an object from equilibrium is called the AMPLITUDE
• the time that it takes to complete one full cycle (A → B → C → B → A) is called the PERIOD of the motion
• if we count the number of full cycles the oscillator completes in a given time, that is called the FREQUENCY of the oscillator

period and frequency

• The period T and frequency f are related to each other.
• if it takes ½ second for an oscillator to go through one cycle, its period is T = 0.5 s.
• in one second, then the oscillator would complete exactly 2 cycles (f = 2 per second or 2 Hertz, Hz)
• 1 Hz = 1 cycle per second.
• thus the frequency is: \( f = \frac{1}{T} \) and, \( T = \frac{1}{f} \)

Mass hanging from a spring

• a mass hanging from a spring also executes harmonic motion up and down.
• to understand this motion we have to first understand how springs work.

springs are amazing devices!

• the harder I pull on a spring, the harder it pulls back
• the harder I push on a spring, the harder it pushes back
Springs obey Hooke’s Law

- The strength of a spring is measured by how much force it provides for a given amount of stretch.
- We call this quantity $k$, the spring constant in N/m.
- The magnitude of spring force is $k \cdot \text{amount of stretch}$.

Springs help you sleep more comfortably!

The mass/spring oscillator

- As the mass falls down, it stretches the spring, which makes the spring force bigger, thus slowing the mass down.
- After the mass has come momentarily to rest at the bottom, the spring pulls it back up.
- At the top, the mass starts falling again and the process continues – oscillation!

The mass spring oscillator does not need gravity

- The time to complete an oscillation does not depend on where the mass starts!

$T = \text{period, time for one complete cycle}$

<table>
<thead>
<tr>
<th>Pendulum</th>
<th>Mass-spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{pendulum}} = 2\pi \sqrt{\frac{L}{g}}$</td>
<td>$T_{\text{mass-spring}} = 2\pi \sqrt{\frac{m}{k}}$</td>
</tr>
</tbody>
</table>

- $L$ = length (m)
- $g = 10$ m/s²
- Does not depend on mass
- $m$ = mass in kg
- $k$ = spring constant in N/m