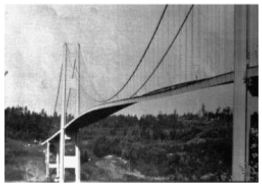
L 20 – Vibration, Waves and Sound -1

- Resonance
- The pendulum
- Springs
- Harmonic motion
- Mechanical waves
- Sound waves
- Musical instruments



Tacoma Narrows Bridge
November 7, 1940
http://www.youtube.com/watch?v=xox9BVSu7Ok

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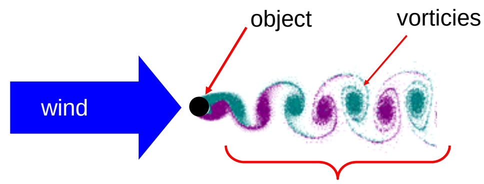
Flow past an object



vortex street - exerts a periodic force on the object

an example of *resonance* in mechanical systems

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Tacoma Narrows Bridge Collapse

- Over Puget Sound in Tacoma, WA
- Opened 1 July 1940, collapsed 7 Nov. 1940
- Puget sound known for very high winds, 40 mph cross winds on Nov. 7
- Wind produced external periodic forcing in resonance with bridge's natural frequency
- Effect know as aerodynamic flutter
- Votrex street downstream produces periodic force on bridge at bridge's natural frequency —resonance phenomenon

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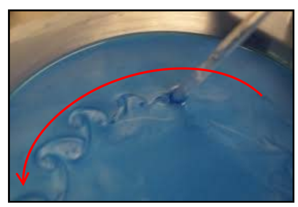
Vortex street behind Selkirk Island



Vortex street behind a cylinder in rotating liquid

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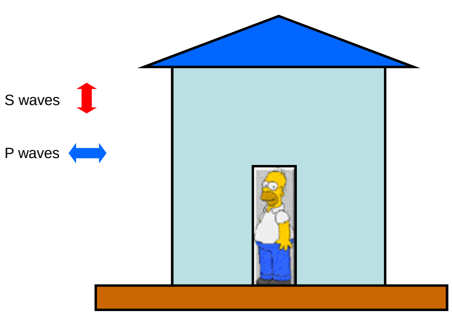
The earth is shaking



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Resonance in systems

- Resonance is the tendency of a system to oscillate with greater amplitude at some frequencies than others– call this f_{res}
- Resonance occurs when energy from one system is transferred to another system
- Example: pushing a child on a swing

To make the child swing higher you must push her at time intervals corresponding to the resonance frequency.

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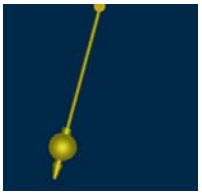
The Pendulum



- First used by Galileo to measure time
- It is a good timekeeping device because the period (time for a complete cycle) does not depend on its mass, and is approximately independent of amplitude (starting position)
- The pendulum is an example of a harmonic oscillator– a system which repeats its motion over and over again

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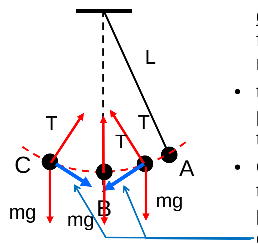
The pendulum- a closer look



- 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, then reverses direction.

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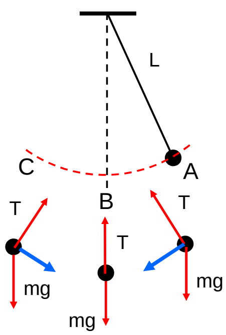
The “restoring” force



- 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

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the role of the restoring force

- the restoring force is the key to understanding 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

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Simple harmonic oscillator

- if there are no drag forces (friction or air resistance) to interfere with the motion, the motion repeats itself forever → we call this a *simple harmonic oscillator*
- *harmonic* – repeats at regular intervals
- The time over which the motion repeats is called the period of oscillation
- The number of times each second that the motion repeats is called the frequency

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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, then gravity pulls it down again

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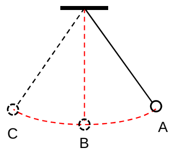
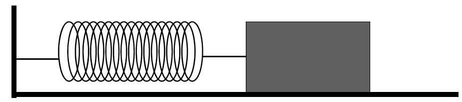
Energy of a pendulum



If there is no friction or air resistance, the total energy of the pendulum, E = KE + GPE is constant.

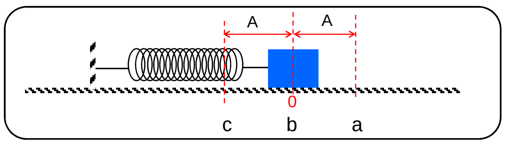
POSITION	ENERGY	COMMENTS
A	GPE	starting position at rest
A → B	KE + GPE	falling and speeding up
B	KE	maximum speed
B → C	KE + GPE	rising and slowing down
C	GPE	momentarily at rest
C → B	KE + GPE	falling and speeding up
B	KE	maximum speed
B → A	KE + GPE	rising and slowing down
A	GPE	momentarily at rest

The horizontal mass/spring system on the air track – a prototype simple harmonic oscillator



- Gravity plays no role in this simple harmonic oscillator
- The restoring force is provided by the spring

Terminology of simple harmonic motion

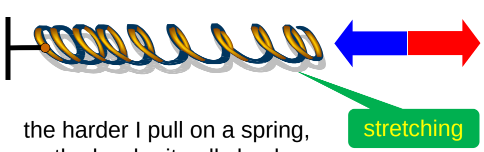


- the maximum displacement of an object from equilibrium **(0)** is called the **AMPLITUDE**
- the time that it takes to complete one full cycle (a → b → c → b → a) is called the **PERIOD**
- if we count the number of full cycles the oscillator completes in a given time, that is called the **FREQUENCY** of the oscillator

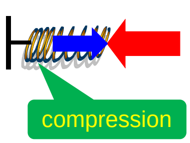
period and frequency

- 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: $f = 1/T$ and, $T = 1/f$

springs are amazing devices!

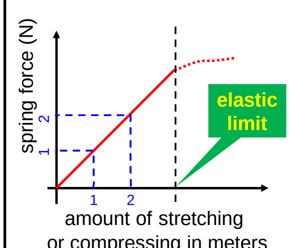


the harder I pull on a spring, the harder it pulls back



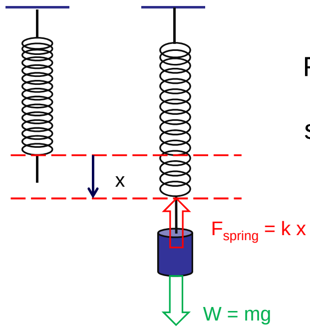
the harder I push on a spring, the harder it pushes back

Springs obey Hooke's Law



- The strength of a spring is measured by how much force it provides for a given amount of stretch
- The force is proportional to the amount of stretch, F ∝ x (Hooke's Law)
- A spring is characterized by the ratio of force to stretch, a quantity k called the spring constant measured in N/m
- A "stiffer" spring has a larger value of k

The spring force



$$F_{spring} = kx = mg$$

$$\text{so,} \quad x = \frac{mg}{k}$$

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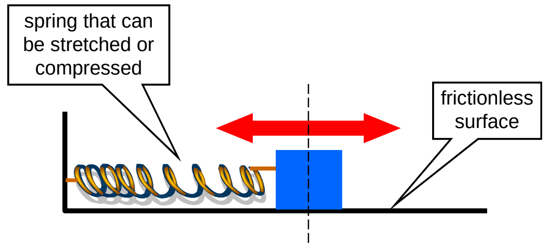
The horizontal mass spring oscillator



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

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The period (T): time for one *complete* cycle

PENDULUM	MASS/SPRING
$T_{pendulum} = 2\pi\sqrt{\frac{L}{g}}$	$T_{mass-spring} = 2\pi\sqrt{\frac{m}{k}}$
• L = length (m) • g = 10 m/s^2 • does not depend on mass • for L = 1 m,	• m = mass in kg • k = spring constant in N/m
$T \approx 2\pi\sqrt{\frac{1m}{10\,m/s^2}} \approx \frac{2\pi}{\sqrt{10}} \approx 2\ s$	

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