Lecture 1

Physics 106
Spring 2007

http://web.njit.edu/~sirenko/

Instructor:

Prof. Andrei Sirenko

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- Office hours: Wednesday 2:30 – 4:00 pm
- Friday 11:30 – 1:00 pm

or by appointment

Course information:

- Physics 106:

Continuation of Classical Mechanics:

- Rotation and Circular motion
- Harmonic Oscillations
- Gravitation

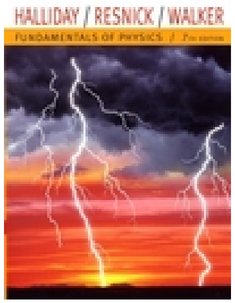
Course Elements:

- Textbook
- Lectures (lecture notes)
- Recitations
- Homework (due at the beginning of the next Recitation)
- Exams (3 common exams, final exam)
- Workshop
- Lab (separate grade)

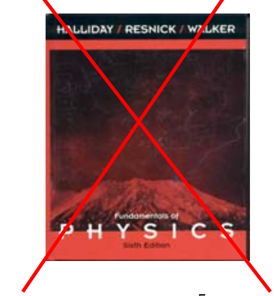
Textbook:

Halliday, Resnick, and Walker (HR&W)
Fundamentals of Physics, 7th edition
Chapters 10-15th Volume 1

7th edition:



6th edition:

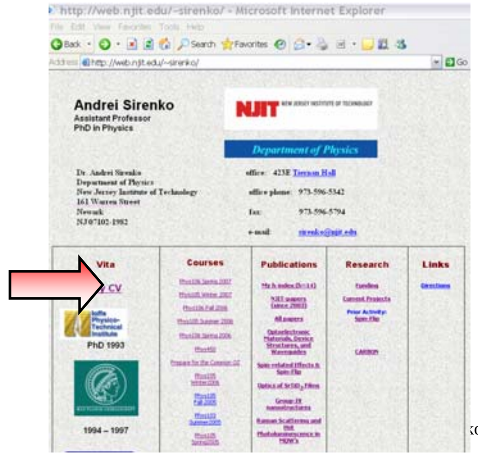


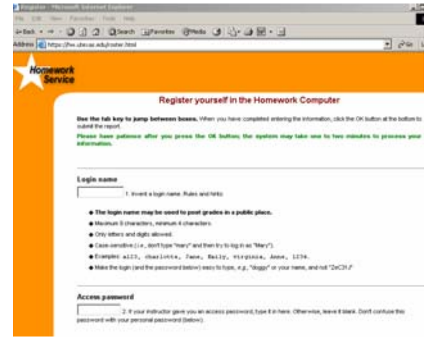
Web Page:

http://web.njit.edu/~sirenko/

and click "Phys 106 Spring 2007"

UTexas:
Class: 11787





Lectures: (Wednesdays 1:00 pm; TH107)

- Presentation of the concepts and techniques of Physics.
- Demonstrations of Physics in action.
- Lecture quiz at the end of every lecture
- Lectures are not a substitute for reading the text!
  Text chapters are listed on the lecture schedule.
  Read ahead; you'll get more from lecture.
- Slides will be posted on the course web.
  Use these as a study guide/note taking aid.

Recitations (10:00 am; TH107)

- Recitations provide an opportunity to do a group activity relevant to the topic being studied, and to ask homework questions.
- The scenarios presented in the recitation group activities will be on the exams.

Grade Components:

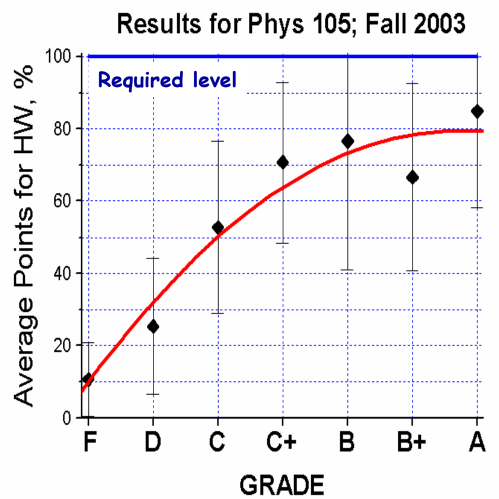
- **48%** for all three common exams (16% each)
- **32%** for the final exam
- **8%** for the total homework grade
- **4%** for the total lecture quiz grade
- **8%** for the workshop grade submitted by your WS instructor

"Phys 106 Workshop assignments will be posted at the course WebCT site at http://webct.njit.edu/; enter your UCID and password to have an access to this site. Please contact the Help Desk at 973-596-2900 for questions regarding your UCID and password."

"Students are required to bring their own printed copies to the WS and Recitation class."

How to Do Well

- Keep up!
- Do the homework carefully and understand the reason for each step.
- Form a study group to discuss homework problems.
- Do plenty of extra problems and examples.
- The material gets more difficult through the term. Don't slack off if you are doing well !

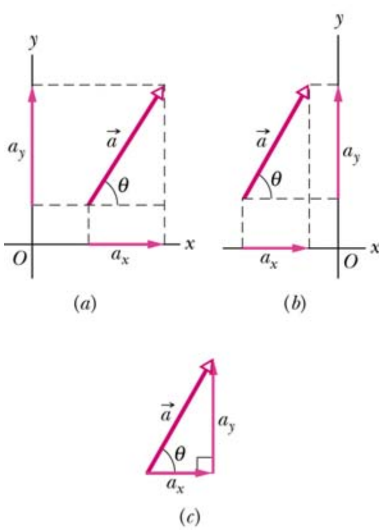


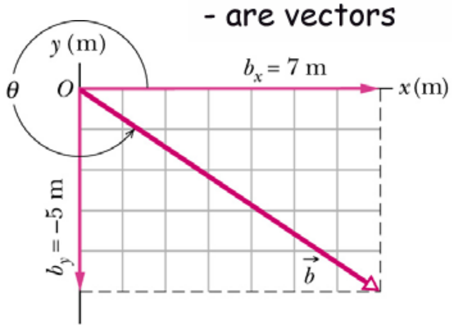
What should we know ?

- **Vectors**
  addition, subtraction, scalar multiplication
- **Trigonometric functions**
  $\sin\theta$, $\cos\theta$, $\tan\theta$, $\theta = \tan^{-1}(a/b)$, *etc.*
- **Integration and Derivatives (basic concepts)**
  $2x = (x^2)'$
- **SI Units**
- **Newton's Laws**
  $F = ma$ $F_{12} = -F_{21}$
- **Energy Conservation**
  Kinetic Energy, Potential Energy, and Work
- **Circular motion and Centripetal Force**
  $a_c = v^2/R$

Components of Vectors:

- aligned along axis
- add to give vector
- are vectors





$$a_x = a\cos\theta \quad \text{and} \quad a_y = a\sin\theta$$

$$a = \sqrt{a_x^2 + a_y^2} \quad \text{and} \quad \tan\theta = \frac{a_y}{a_x}$$

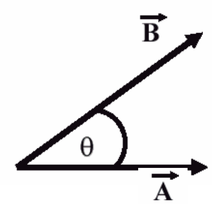
Length (Magnitude)

Vector Multiplication

Dot product

$$\vec{A} \bullet \vec{B} = AB\cos\theta = A_xB_x + A_yB_y + A_zB_z$$

θ is the angle between the vectors if you put their tails together



$\vec{A} \bullet \vec{B} = \vec{B} \bullet \vec{A}$

since $\cos(\theta) = \cos(-\theta)$

TABLE 2-1 Equations for Motion with Constant Acceleration[a]

Equation Number	Equation	Missing Quantity
2-11	$v = v_0 + at$	$x - x_0$
2-15	$x - x_0 = v_0 t + \frac{1}{2}at^2$	v
2-16	$v^2 = v_0^2 + 2a(x - x_0)$	t
2-17	$x - x_0 = \frac{1}{2}(v_0 + v)t$	a
2-18	$x - x_0 = vt - \frac{1}{2}at^2$	v_0

[a] Make sure that the acceleration is indeed constant before using the equations in this table.

What does zero mean ?

- $t = 0$ beginning of the process
- $x = 0$ is arbitrary; can set where you want it
- $x_0 = x(t=0)$; position at t=0; do not mix with the origin

- $v(t) = 0$ x does not change $x(t) - x_0 = 0$
- $v_0 = 0$ $v(t) = at$; $x(t) - x_0 = at^2/2$
- $a = 0$ $v(t) = v_0$; $x(t) - x_0 = v_0 t$

- $a \neq 0$ $v(t) = v_0 + at$; $x(t) - x_0 = v_0 t + at^2/2$

help: $t = (v - v_0)/a$ $x - x_0 = \frac{1}{2}(v^2 - v_0^2)/a$

$a = (v - v_0)/t$ $x - x_0 = \frac{1}{2}(v + v_0)t$

- Acceleration and velocity are positive in the same direction as displacement is positive

Newton's Laws

I. If no net force acts on a body, then the body's velocity cannot change.

II. The net force on a body is equal to the product of the body's mass and acceleration.

III. When two bodies interact, the force on the bodies from each other are always equal in magnitude and opposite in direction ($\mathbf{F}_{12} = -\mathbf{F}_{21}$)

Force is a vector
Force has direction and magnitude
Mass connects Force and acceleration;

$$\vec{F}_{tot} = 0 \Leftrightarrow \vec{a} = 0 \text{ (constant velocity)}$$

$$\vec{F}_{tot} = m\vec{a} \text{ for any object}$$

$$F_{tot,x} = ma_x \qquad F_{tot,y} = ma_y \qquad F_{tot,z} = ma_z$$

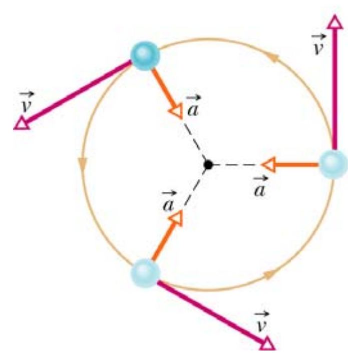
Uniform Circular Motion

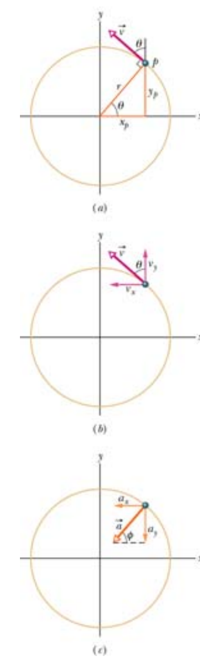
Centripetal acceleration

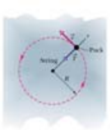
$$a = \frac{v^2}{r}$$

Period

$$T = \frac{2\pi r}{v}$$



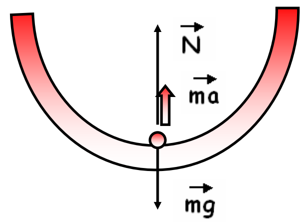




$ma_c = mv^2/R = \Sigma F$

(all forces along the direction towards the center)

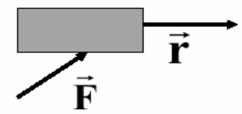
- Gravitational Force: $\vec{mg}$
  down to the ground
- Tension Force: $\vec{T}$
  along the string
- Normal Force: $\vec{N}$
  perpendicular to the support
- Static Friction Force
  maximum value $F_{fr}^{max} = \mu_{st} N$



$ma = N - mg$

$ma = mv^2/R$

What does $W = \vec{F} \bullet \vec{r}$ mean?



$W = \vec{F} \bullet \vec{r}$
$= F_x r_x + F_y r_y$
$= Fr\cos\theta$

W > 0 if $\theta < 90°$ ⟶ force is adding energy to object

W < 0 if $\theta > 90°$ ⟶ force is reducing energy of object

W = 0 if $r = 0$ or $F = 0$ or $\vec{F} \perp \vec{r}$

Work Examples

Push on a wall

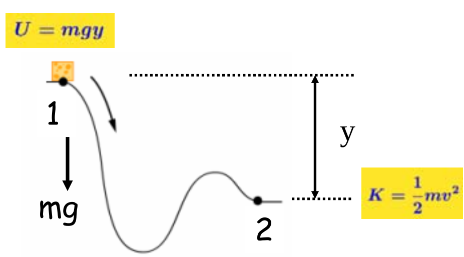
W = 0 since wall does not move ($\vec{r} = 0$)

Kinetic Energy: $K = \frac{1}{2}mv^2$

Potential Energy:

$\Delta U = -W$

- Gravitation: $U = mgy$
- Elastic (due to spring force): $U = \frac{1}{2}kx^2$



U → K

Conservation of Mechanical Energy

$E_{mec} = K + U$

$K_2 + U_2 = K_1 + U_1$

Kinetic Energy: $K = \frac{1}{2}mv^2$

Potential Energy:

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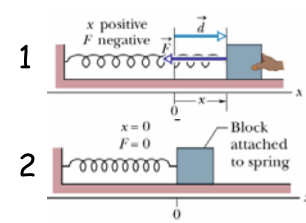


1: $U = \frac{1}{2}kx^2$, K = 0

2: U = 0, $K = \frac{1}{2}mv^2$

U ← → K

Conservation of Mechanical Energy

$E_{mec} = K + U$

$K_2 + U_2 = K_1 + U_1$

Examples for Energy Conservation

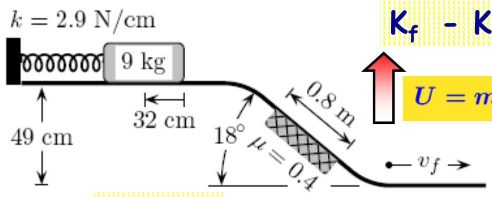
Kinetic Energy changes $K = \frac{1}{2}mv^2$

\+ Gravitational Potential Energy $U = mgy$

\+ Elastic Potential Energy $U = \frac{1}{2}kx^2$

Total Mechanical Energy = *Const.*

$U = \frac{1}{2}kx^2$ → $K = \frac{1}{2}mv^2$



$K_f - K_i = W = mgy - |W_{friction}|$

$U = mgy$

$K = \frac{1}{2}mv^2$

$W_{friction}$

$E_f - E_i = -|W_{friction}| = f_k \cdot d \cdot \cos 180° = -mg\,\mu \cdot d \cdot \cos 18°$

Linear Momentum

Particle: $\vec{p} = m\vec{v}$

System of Particles: $\vec{P} = m_1\vec{v}_1 + m_2\vec{v}_2 + \ldots$

Extended objects: $\vec{P} = M\vec{v}_{com}$

Relation to Force: $\vec{F}_{tot} = m\vec{a}$

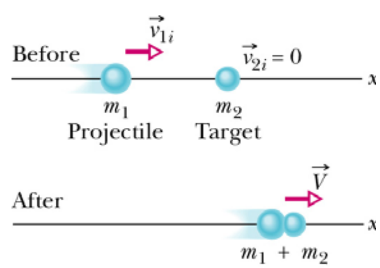
$$\vec{F}_{net} = \frac{d\vec{p}}{dt}$$

$$\vec{F}_{net} = \frac{d\vec{P}}{dt}$$

Completely Inelastic Collision
Collisions in 1D

Conservation of Linear Momentum works !

$\vec{p}_{1i} + \vec{p}_{2i} = \vec{p}_{1f} + \vec{p}_{2f}$



$$m_1 v_{1i} = (m_1 + m_2)V$$

$$V = \frac{m_1}{m_1 + m_2} v_{1i}$$

Example: Two equal objects, one initially at rest

$mv_i = 2mv_f$ ⟶ $v_f = v_i/2$

Final Kinetic Energy = $\frac{1}{2}(2m)(v_i/2)^2$

$= \frac{1}{4}m(v_i)^2$

Half the original Kinetic Energy

Lecture 1

Rotation concepts & variables.

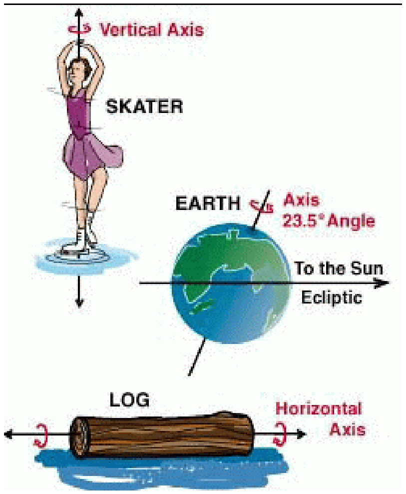
Motion diagrams, FBD's.

Rotation kinematics

Chapter 10 (1-5)

http://web.njit.edu/~sirenko/

Rotation; Examples



http://www.ce.utexas.edu/prof/olivera/Earth.htm

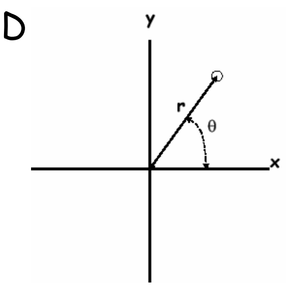
Rotational Motion

- 33 1/3 rpm
- 45 rpm

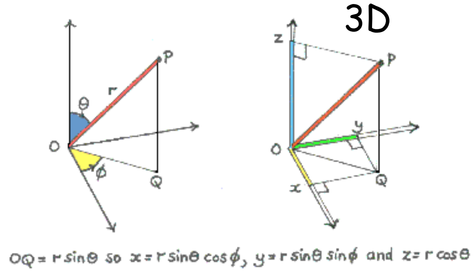
Uniform Circular Motion:
Spinning at steady rate

Changing x,y,z coordinates into spherical polar coordinates

2D



3D



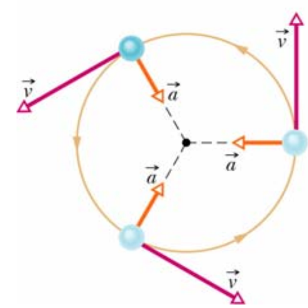
$r = \sqrt{x^2 + y^2}$
$\theta = \tan^{-1}(y/x)$ ⇔ $x = r\cos(\theta)$
$y = r\sin(\theta)$

Uniform Circular Motion
(Phys 105)

Object travels around a circle at constant speed

Centripetal acceleration

$$a = \frac{v^2}{r}$$



Period: T = 2πr/v ≡ time to go around once

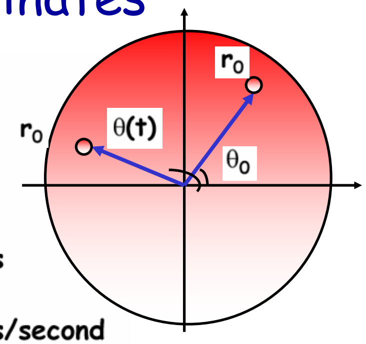
Uniform Circular Motion in Polar Coordinates

$\theta(t) = \omega t + \theta_0$

$r = r_0$

θ	angular position	radians
ω	angular velocity	radians/second

$\omega = v/r$ where v is the linear speed around the circle

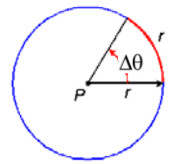


Linear velocity along circle: $v = ds/dt$

$= r d\theta/dt$

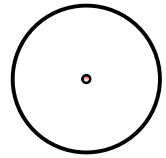
$v = r\omega$

Radian



1 Radian = $180° / \pi \approx 57.3°$

The arc length is equal to the radius $\Delta s = r\Delta\theta$



Circle: $360° = 2\pi$ radians ≈ 6.283 radians

$\frac{1}{2}$ Circle: $180° = \pi$ radians ≈ 3.1415 radians

- Radians = degrees $\times$ (π /180)
- 1 degree = π /180=0.0174532925 radians.
- 180°= 3.14156 radians
- 90° = 1.5708 radians
- 45° = 0.7854 radians

Angular Acceleration

$$\alpha = \frac{d\omega}{dt}$$

Plays same role in rotational motion as acceleration in linear motion

$$\alpha = 0 \quad \not\Rightarrow \quad \vec{a} = 0$$

Example: uniform circular motion

Angular variables are vectors

Direction of the vector:

Right-hand-rule

Sign of $\Delta\theta$:

"Clocks are negative"

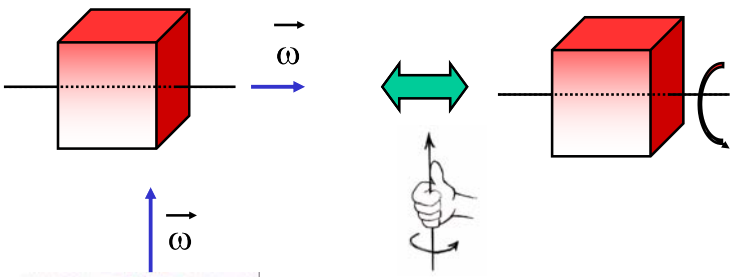
Positive $\Delta\theta$ Negative $\Delta\theta$

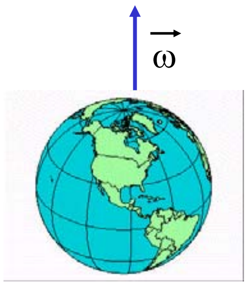
Sign of $\Delta\theta$ and ω is the same: $\omega = \Delta\theta/\Delta t$

$\omega = d\theta/dt$

Signs of ω and α can be the same of different

Example:





The length of the vector $\vec{\omega}$ is proportional to the magnitude of ω

Rotational Kinematics:

Linear Displacement	↔	Angular Displacement
Linear Velocity	↔	Angular Velocity
Linear Acceleration	↔	Angular Acceleration

$$\vec{x},\ \vec{v},\ \vec{a} \Leftrightarrow \vec{\theta},\ \vec{\omega},\ \vec{\alpha}$$

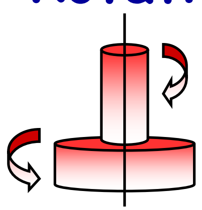
If α is constant:

$$\theta(t) = \theta_0 + \omega_0 t + \tfrac{1}{2}\alpha t^2$$

$$\omega = \frac{d\theta}{dt} \rightarrow \quad \omega(t) = \omega_0 + \alpha t$$

$$\text{combine: } 2\alpha\,(\theta - \theta_0) = \omega^2 - \omega_0^2$$

Rotation:



Angular Displacement
Angular Velocity
Angular Acceleration

$$\theta,\ \vec{\omega},\ \vec{\alpha}$$

Linear Equation	Missing Variable		Angular Equation
$v = v_0 + at$	$x - x_0$	$\theta - \theta_0$	$\omega = \omega_0 + \alpha t$
$x - x_0 = v_0 t + \frac{1}{2}at^2$	v	ω	$\theta - \theta_0 = \omega_0 t + \frac{1}{2}\alpha t^2$
$v^2 = v_0{}^2 + 2a(x - x_0)$	t	t	$\omega^2 = \omega_0{}^2 + 2\alpha(\theta - \theta_0)$
$x - x_0 = \frac{1}{2}(v_0 + v)t$	a	α	$\theta - \theta_0 = \frac{1}{2}(\omega_0 + \omega)t$
$x - x_0 = vt - \frac{1}{2}at^2$	v_0	ω_0	$\theta - \theta_0 = \omega t - \frac{1}{2}\alpha t^2$

TABLE 2-1 Equations for Motion with Constant Acceleration[a]

Equation Number	Equation	Missing Quantity
2-11	$v = v_0 + at$	$x - x_0$
2-15	$x - x_0 = v_0 t + \frac{1}{2}at^2$	v
2-16	$v^2 = v_0^2 + 2a(x - x_0)$	t
2-17	$x - x_0 = \frac{1}{2}(v_0 + v)t$	a
2-18	$x - x_0 = vt - \frac{1}{2}at^2$	v_0

[a] Make sure that the acceleration is indeed constant before using the equations in this table.

Homework

See the Physics 106 Course Syllabus

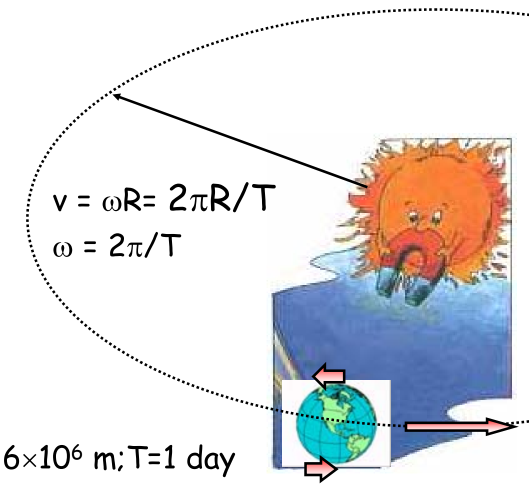
FOP Chapter 10:

U of Texas: Register for the Class 11787
And start working on the first HW!
Bring the printouts to the Recitation class

http://web.njit.edu/~sirenko/

QZ: Our linear velocity with respect to the Sun

$R_{E\text{-}S} = 1.5\times10^{11}$ m T=1 year = 365 days



$v = \omega R = 2\pi R/T$

$\omega = 2\pi/T$

$R = 6\times10^{6}$ m; T=1 day

When do we move faster ?
(a) Day
(b) Night

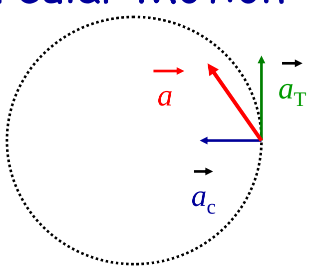
What is the velocity difference between Day and Night at the Equator line ?
$|(V_{day} - V_{night})|/V_{average}$
(a) 0.00008
(b) 0.015
(c) 0.03
(d) 0.3
(e) 100 %

Show work !

Acceleration in Circular Motion:

General Case:
The velocity changes with time.

ω is not constant ($\alpha \neq 0$)



There are two components of **acceleration**:

- **Centripetal** (radial, towards the center) and
- **Tangential** (along the velocity vector)
- Total acceleration value:

$$a_c = v^2/r = r\,\omega^2$$

$$a_T = r\,\alpha$$

$$\vec{a} = \vec{a}_c + \vec{a}_T \,; \quad a = (a_c^2 + a_T^2)^{1/2},\ \tan\phi = a_T / a_c$$