PHYS 1441 – Section 002
Lecture #10

Wednesday, Mar. 4, 2009

Dr. Jaehoon Yu

- Exam Solutions
- Application of Newton's Laws
  - Motion without friction
- Forces of Friction
  - Motion with friction

Announcements

- Changes of Exam Dates
  - Mid-term exam scheduled on Mar. 11 now moved to Wed. Mar. 25
  - Second non-comprehensive exam scheduled on Apr. 13 now moved to Wed. Apr. 22
  - Final comprehensive exam stays on the same date, May 11
- A fun colloquium today
  - Physics of NASCAR at 4pm in SH101

Physics Department
The University of Texas at Arlington

COLLOQUIUM

Materials at 200 MPH: Making Nascar Faster and Safer

Dr. Diandra Leslie-Pelecky
The University of Texas at Dallas

4:00 pm Wednesday March 4, 2009 Room 101 SH

Abstract

You cannot win a NASCAR race without understanding science.[1] Materials play important roles in improving performance, but also in ensuring safety. On the performance side, NASCAR limits the materials race car scientists and engineers can use to limit ownership costs. 'Exotic metals' are not allowed, so controlling microstructure and nanostructure are important tools in producing materials that maximize strength while minimizing weight. Compacted Graphite Iron, a cast iron in which magnesium additions produce interlocking microscale graphite reinforcements, makes engine blocks stronger and lighter. NASCAR's new car design employs an innovative polymer composite called Tegris™ in the splitter. This composite can replace significantly more expensive carbon-fiber composites in many applications.

The most important role of materials in racing is safety. Drivers wear firesuits made of polymers that carbonize (providing thermal protection) and expand (reducing oxygen availability) when heated. Catalytic materials originally developed for space-based CO_2 lasers filter air for drivers during races. Although materials help cars go fast, they also help cars slow down safely—important because the kinetic energy of a race car going 180 mph is nine times greater than that of a passenger car going 60 mph. Energy-absorbing foams in the cars and on the tracks direct energy dissipation away from the driver during accidents.

NASCAR fans–and there are about 75 million of them–understand that science and engineering are integral to keeping their drivers safe and helping their teams win. Their passion for racing gives us a great opportunity to share our passion for materials science and engineering with them.

1. Diandra Leslie-Pelecky, *The Physics of NASCAR* (Dutton, New York City, 2008).

Refreshments will be served in the Physics Library at 3:30 pm

Problems 10 – 14]

- A car starts from rest and accelerates with the acceleration $\vec{a} = -5\hat{i}\left(m/s^2\right)$ for 15 s. It then travels at a constant speed for 50s and then slows down at the rate of 1 m/s^2 to a full stop. Ignore road friction and air resistance. Be sure to express vector quantities in vector form.

10. What is the velocity after 40s from the start?

Solution: Since the acceleration is applied only in x-direction for the first 15s, the velocity at 15 seconds is the same as that at 40s from the start. Using the kinematic equation, we obtain

$$a_x = -5\,m/s^2 \qquad a_y = 0\,m/s^2$$

$$v_{x,t=40} = v_{x,t=15} = v_{xi} + a_x t = 0 + (-5)\cdot 15 = -75\left(m/s\right)$$

$$v_{y,t=40} = v_{y,t=15} = v_{yi} + a_y t = 0 + (0)\cdot 15 = 0\left(m/s\right)$$

$$\vec{v}_{t=40} = \vec{v}_{t=15} = v_{x,t=40}\vec{i} + v_{y,t=40}\vec{j} = -75\vec{i} + 0\vec{j} = -75\vec{i}\left(m/s\right)$$

Problems 10 – 14]

- A car starts from rest and accelerates with the acceleration $\vec{a} = -5\hat{i}\left(m/s^2\right)$ for 15 s. It then travels at a constant speed for 50s and then slows down at the rate of 1 m/s^2 to a full stop. Ignore road friction and air resistance. Be sure to express vector quantities in vector form.

11. What is the total displacement after 50s from the start?

Solution: We divide the motion in two segments: one from 0 – 15s where the car was accelerated and 15 – 50, the 35 s period the car was running at the constant velocity of . Using the kinematic equation, we obtain

$$\Delta x = x_f - x_i = v_{xi}t + \frac{1}{2}a_x t^2; \quad \Delta y = y_f - y_i = v_{yi}t + \frac{1}{2}a_y t^2$$

$$\Delta x_{0-15s} = 0 \cdot 15 + \frac{1}{2}\cdot(-5)\cdot(15)^2 = -563(m)$$

$$\Delta x_{15-50s} = (-75)\cdot 35 + \frac{1}{2}\cdot 0 \cdot (35)^2 = -2625(m);$$

$$\Delta y_{0-50s} = \Delta y_{0-\infty s} = 0\cdot\infty + \frac{1}{2}\cdot(0)\cdot(\infty)^2 = 0(m)$$

$$\therefore \Delta\vec{r}_{0-50s} = \left(\Delta x_{0-15s} + \Delta x_{15-50s}\right)\vec{i} + \Delta y_{0-50s}\vec{j} = (-563 - 2625)\vec{i} + 0\vec{j} = -3188\vec{i}m$$

Problems 10 – 14]

- A car starts from rest and accelerates with the acceleration $\vec{a} = -5\hat{i}\left(m/s^2\right)$ for 15 s. It then travels at a constant speed for 50s and then slows down at the rate of 1 m/s^2 to a full stop. Ignore road friction and air resistance. Be sure to express vector quantities in vector form.

12. What is the velocity after 100s from the start??

Solution: Since the acceleration in opposite direction was applied on the car from 65s after the start of the motion at which time the car was running at a constant velocity, $\vec{v} = -75\vec{i}\ m/s$. Using kinematic equation, we obtain

What is the acceleration? $\vec{a} = +1\vec{i}\ m/s^2 \quad \Rightarrow a_x = +1 m/s^2;\ a_y = 0\, m/s^2$

$$v_{x,t=100} = v_{x,t=65} + a_x t = -75 + (+1)\cdot(100-65) = -75 + (+1)\cdot(35) = -40(m/s)$$

$$v_{y,t=100} = v_{y,t=65} + a_y t = 0 + (0)\cdot(100-65) = 0 + (0)\cdot(35) = 0(m/s)$$

$$\vec{v}_{t=100} = v_{x,t=100}\vec{i} + v_{y,t=100}\vec{j} = -40\vec{i} + 0\vec{j} = -40\vec{i}(m/s)$$

Problems 18 – 21]

- A projectile is launched with a speed of 100 m/s at an angle of 30 ^{o} with respect to the horizontal axis. The magnitude of the gravitational acceleration is 9.8m/s^2. Ignore the air resistance.

18. What is the projectile's maximum altitude?

Solution: From the information given in the problem, we obtain

Initial speed $\left|\vec{v}_0\right| = 100\, m/s$ Launch Angle $\theta = 30^\circ;$

X-component of the initial velocity $v_{x0} = \left|\vec{v}_0\right| \cos 30^\circ = 87\, m/s$

y-component of the initial velocity $v_{y0} = \left|\vec{v}_0\right| \sin 30^\circ = 50\, m/s$

Maximum altitude is determined only by the y component of the displacement!

$$2ax = v_f^2 - v_i^2 \xrightarrow{\text{In y}} 2 \cdot g \cdot y = v_{yf}^2 - v_{y0}^2 \xrightarrow{\text{Solve for y}} y = \frac{v_{yf}^2 - v_{y0}^2}{2 \cdot g}$$

Since at the maximum altitude is y component of the velocity is 0

$$y_{\max} = \frac{0 - 50^2}{2 \cdot (-9.8)} = +128m$$

Problems 18 – 21]

- A projectile is launched with a speed of 100 m/s at an angle of 30 ^{o} with respect to the horizontal axis. The magnitude of the gravitational acceleration is 9.8m/s^2. Ignore the air resistance.

$$v_{x0} = \left|\vec{v}_0\right| \cos 30^\circ = 87\, m/s \qquad v_{y0} = \left|\vec{v}_0\right| \sin 30^\circ = 50\, m/s$$

19.What is the distance of the projectile from the starting point when it lands?

Solution: Since the time the projectile takes to reach back to land is twice the time it takes to reach the maximum altitude.

Which component determines the flight time? y-component

$$v_{yf} = v_{y0} + gt \xrightarrow{\text{Solve for t}} t = \frac{v_{yf} - v_{y0}}{g}; \xrightarrow{\text{Time to reach max altitude}} t_{top} = \frac{v_{yf} - v_{y0}}{g} = \frac{0-50}{-9.8} = 5.1s;$$

Flight time is twice the time to reach the max height!! $\Rightarrow$ $t_{flight} = 2 \cdot t_{top} = 10.2s$

The range is then determined only by the x component of the displacement!

$$\left|\Delta x\right| = \left|x_f - x_0\right| = \left|v_{x0} \cdot t_{flight}\right| = 87 \cdot 10.2 = 887\left(m\right)$$

Problems 18 – 21]

- A projectile is launched with a speed of 100 m/s at an angle of 30 ^{o} with respect to the horizontal axis. The magnitude of the gravitational acceleration is 9.8m/s^2. Ignore the air resistance.

20. What is the projectile's speed when it reaches the maximum altitude?

Solution: Since when the projectile reaches the maximum height the y component of the velocity becomes 0, the speed at the maximum altitude is the same is the magnitude of the x component of the initial velocity.

Initial speed $\left|\vec{v}_0\right| = 100\,m/s$ Launch Angle $\theta = 30^\circ;$

X-component of the initial velocity $v_{x0} = \left|\vec{v}_0\right|\cos 30^\circ = 87\,m/s$

y-component of the initial velocity $v_{y0} = \left|\vec{v}_0\right|\sin 30^\circ = 50\,m/s$

x-component of the final velocity $v_{xf} = v_{x0} = 87\,m/s$

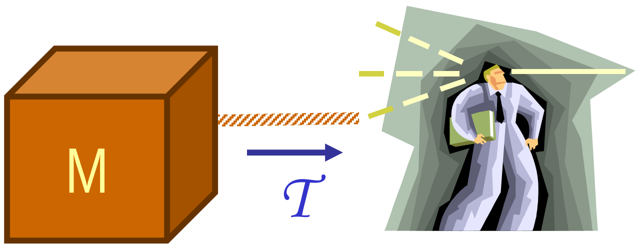
y-component of the final velocity $v_{yf} = 0$

So the final speed is $\therefore \left|\vec{v}_f\right| = \sqrt{v_{xf}^2 + v_{yf}^2} = \sqrt{v_{xf}^2 + 0^2} = v_{xf} = 87\,m/s$

Same as the x-component of the final velocity

Applications of Newton's Laws

Suppose you are pulling a box on frictionless ice, using a rope.



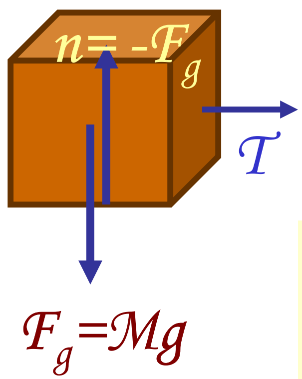
What are the forces being exerted on the box?

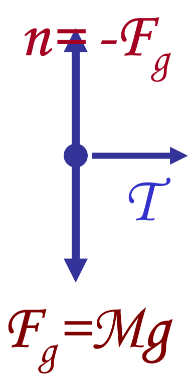
Gravitational force: F_g

Normal force: n

Tension force: T

Free-body diagram





Total force:
$F=F_g+n+T=T$

$$\sum F_x = T = Ma_x \qquad \boxed{a_x = \frac{T}{M}}$$

$$\sum F_y = -F_g + n = Ma_y = 0 \qquad \boxed{a_y = 0}$$

If T is a constant force, a_x, is constant

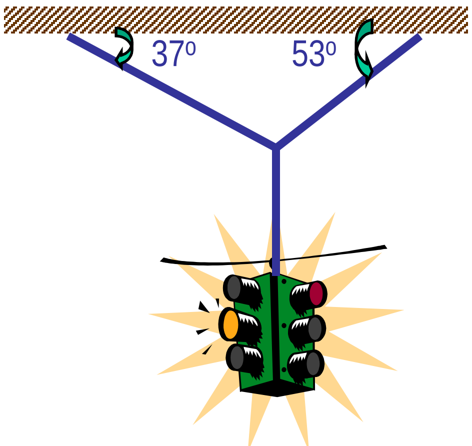
$$v_{xf} = v_{xi} + a_x t = v_{xi} + \left(\frac{T}{M}\right)t$$

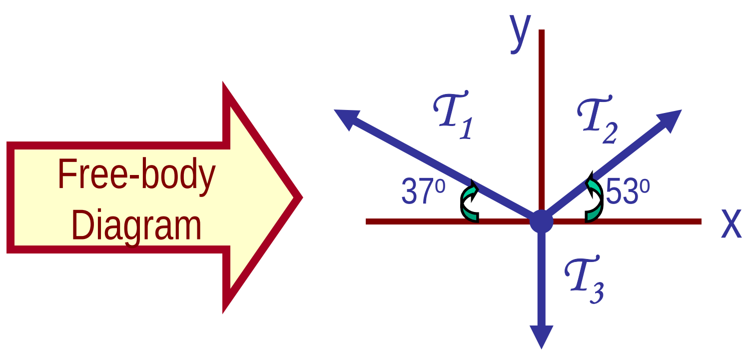
$$\Delta x = x_f - x_i = v_{xi}t + \frac{1}{2}\left(\frac{T}{M}\right)t^2$$

What happened to the motion in y-direction?

Example for Using Newton's Laws

A traffic light weighing 125 N hangs from a cable tied to two other cables fastened to a support. The upper cables make angles of 37.0° and 53.0° with the horizontal. Find the tension in the three cables.





$$\vec{F} = \vec{T}_1 + \vec{T}_2 + \vec{T}_3 = m\vec{a} = 0$$ Newton's 2nd law

x-comp. of net force

$$F_x = \sum_{i=1}^{i=3} T_{ix} = 0 \quad -T_1\cos\left(37^\circ\right) + T_2\cos\left(53^\circ\right) = 0 \therefore T_1 = \frac{\cos\left(53^\circ\right)}{\cos\left(37^\circ\right)} T_2 = 0.754 T_2$$

y-comp. of net force

$$F_y = \sum_{i=1}^{i=3} T_{iy} = 0$$

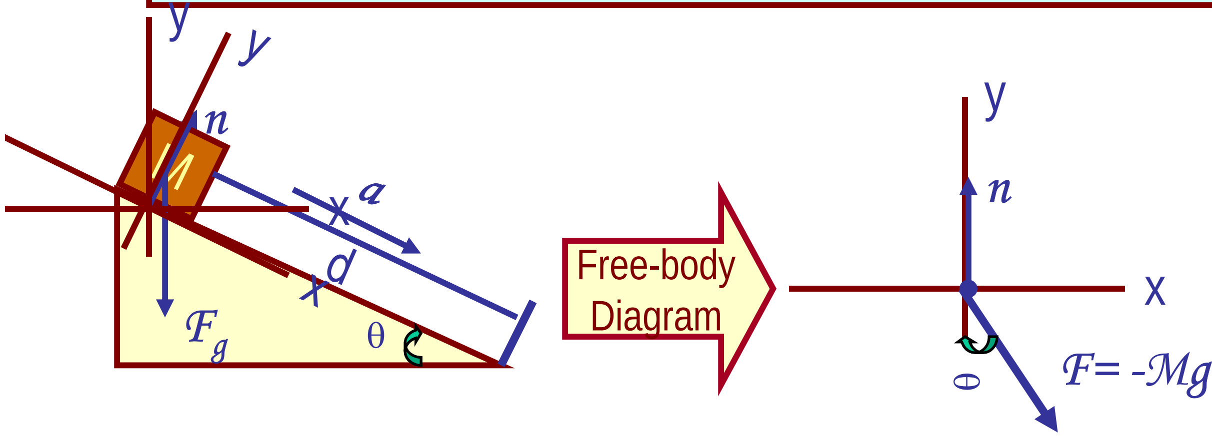
$$T_1\sin\left(37^\circ\right) + T_2\sin\left(53^\circ\right) - mg = 0$$

$$T_2\left[\sin\left(53^\circ\right) + 0.754\times\sin\left(37^\circ\right)\right] = 1.25 T_2 = 125N$$

$$T_2 = 100N; \quad T_1 = 0.754 T_2 = 75.4N$$

Example w/o Friction

A crate of mass M is placed on a frictionless inclined plane of angle θ. Determine the acceleration of the crate after it is released.



$$\vec{F} = \vec{F}_g + \vec{n} = m\vec{a}$$

$$F_x = Ma_x = F_{gx} = Mg\sin\theta$$

$$\boxed{a_x = g\sin\theta}$$

$$F_y = Ma_y = n - F_{gy} = n - mg\cos\theta = 0$$

Supposed the crate was released at the top of the incline, and the length of the incline is d. How long does it take for the crate to reach the bottom and what is its speed at the bottom?

$$d = v_{ix}t + \frac{1}{2}a_x t^2 = \frac{1}{2}g\sin\theta\, t^2$$

$$\boxed{\therefore t = \sqrt{\frac{2d}{g\sin\theta}}}$$

$$v_{xf} = v_{ix} + a_x t = g\sin\theta\sqrt{\frac{2d}{g\sin\theta}} = \sqrt{2dg\sin\theta}$$

$$\boxed{\therefore v_{xf} = \sqrt{2dg\sin\theta}}$$