Rutgers University
Department of Physics & Astronomy

01:750:271 Honors Physics I
Fall 2015

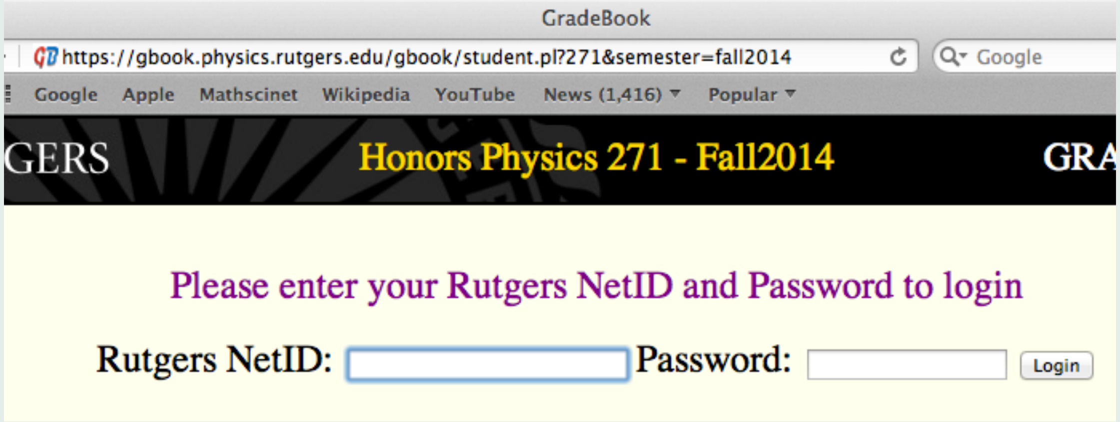
Lecture 7

Midterm 1: Monday October 10th

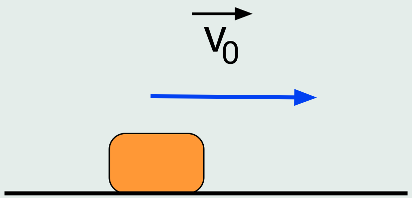
- Motion in one, two and three dimensions
- Forces and Motion I
- No energy and work.
- 1:55-2:50pm in the Physics Lecture Hall

Gradebook

- www.physics.rutgers.edu/ugrad/271



- **Friction**



- Suppose an object is launched with velocity $\vec{v}_0$ along a surface.
- Newton's 1st law: if $\vec{F}_{\text{net}} = 0$ it should move forever with constant velocity $\vec{v}_0$.
- Does it really happen in practice?

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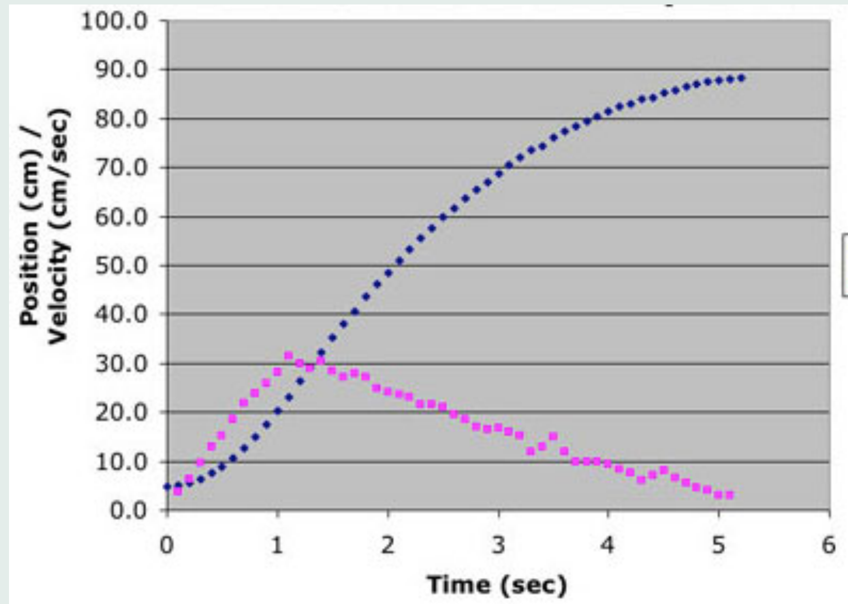
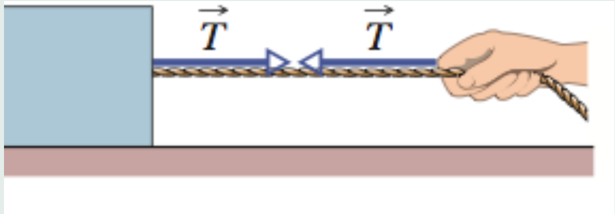
• **Experiment:** a toy truck is quickly accelerated to some velocity $\vec{v}_0$ and then released.



It stops in finite time; x vs time $\sim$ parabola

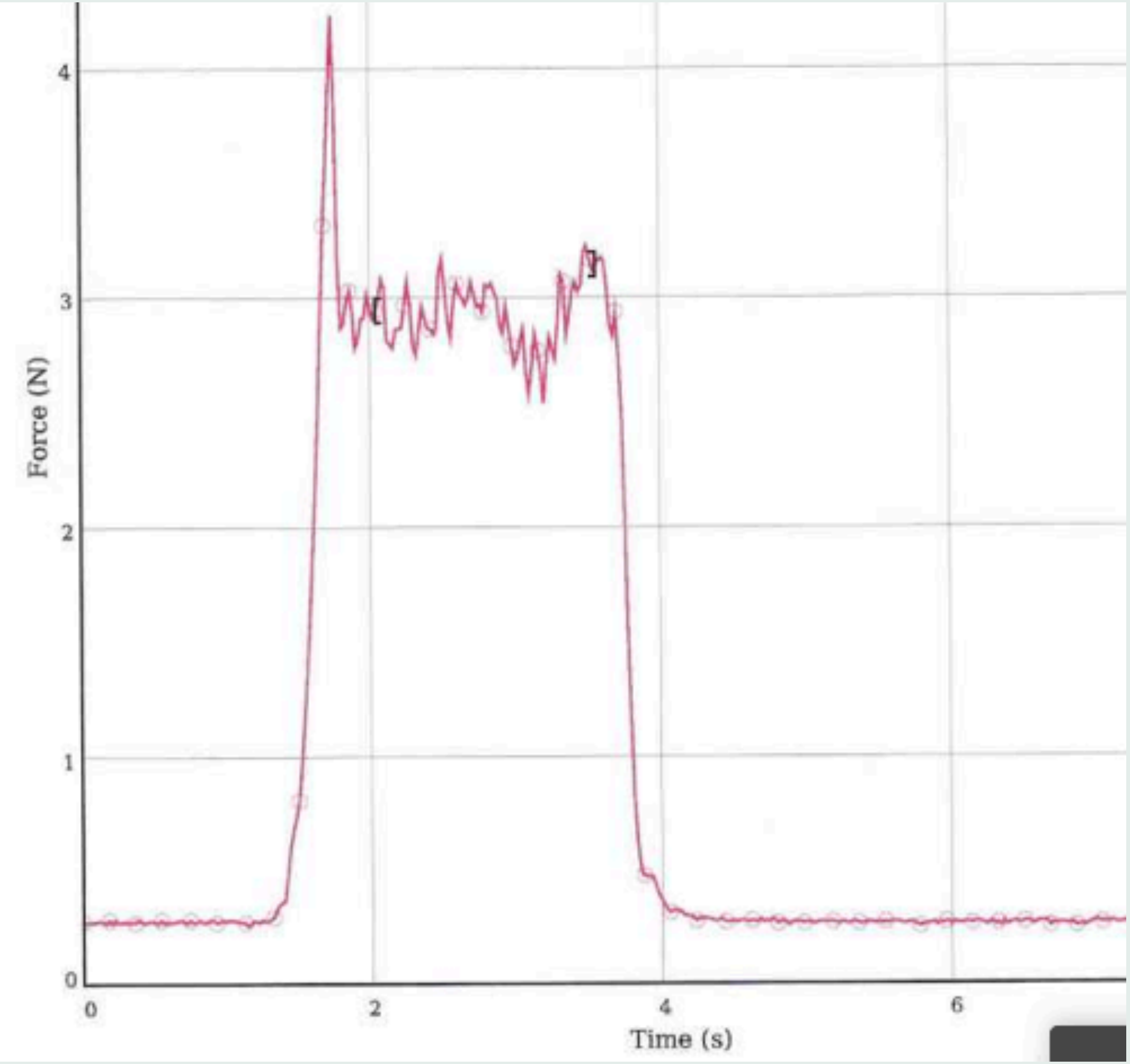
v_x vs time $\sim$ linear once it starts deccelerating $\Rightarrow$ constant negative acceleration

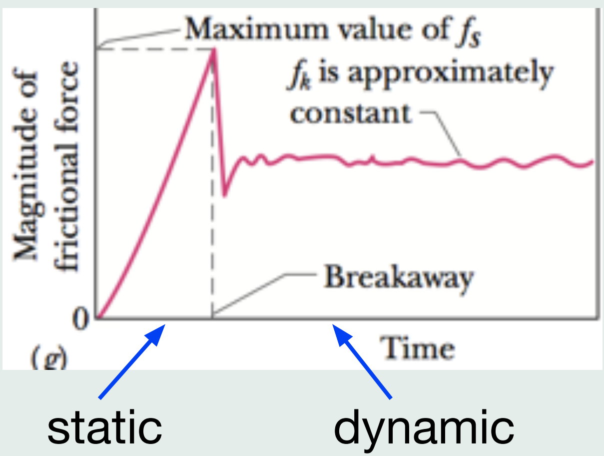


What force is necessary to set a static object in motion and then maintain constant velocity?

Static

In motion


Force (N)
Time (s)
0
1
2
3
4
0
2
4
6



- **Static** friction $\vec{f}_s$ acts when no **relative motion** between object and contact surface.

- The magnitude f_s increases as the applied force increases until it reaches a maximum value $(f_s)_{\text{max}}$.

- **Kinetic** friction $\vec{f}_k$ acts when there is **relative motion** between object and contact surface.

- Usually $f_k < (f_s)_{\text{max}}$.

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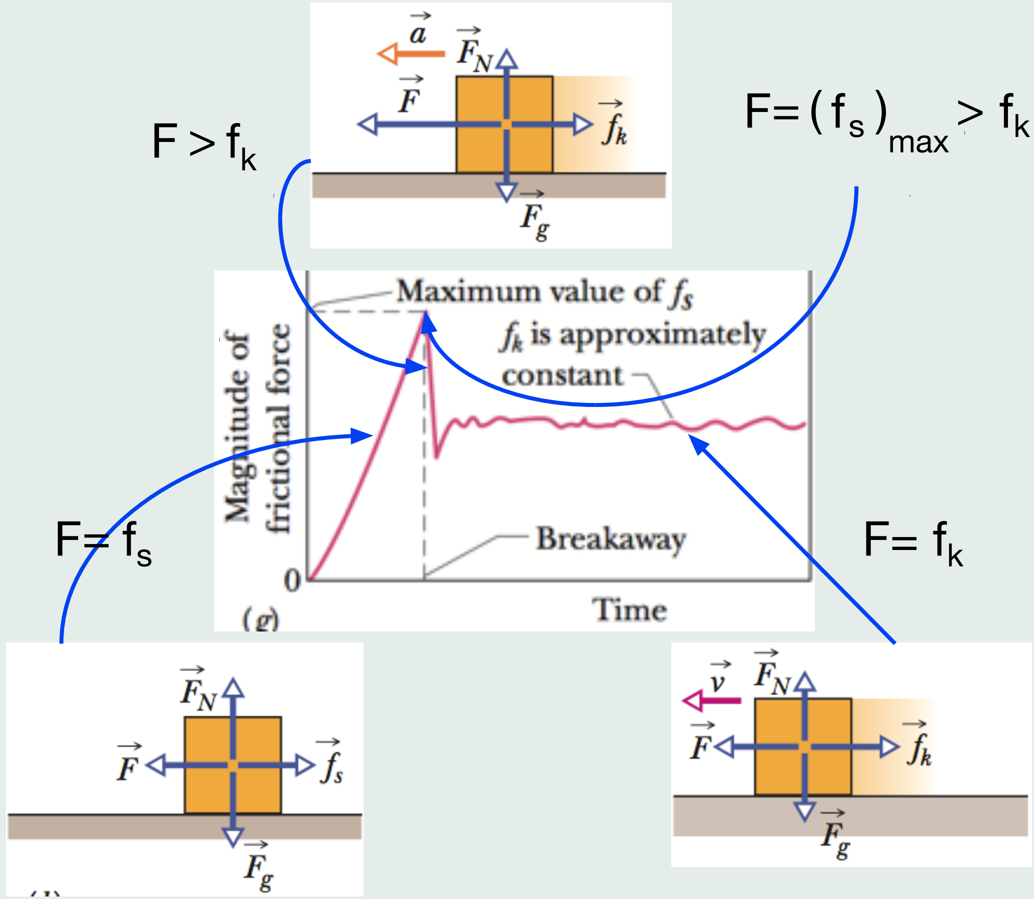
Static

|

Dynamic

Transition



- **Properties of friction**

1. For a stationary object $\vec{F} + \vec{f}_s = 0$ i.e. the applied force and the **static friction** balance each other out.

2. The magnitude of static friction has a **maximum value** depending on the magnitude of the normal force F_N:

$$(f_s)_{\text{max}} = \mu_s F_N$$

where $\mu_s =$ **coefficient of static friction**. When $F \geq (f_s)_{\text{max}}$ the object begins to slide.

3. When sliding begins, the magnitude of friction rapidly decreases to a value

$f_k = \mu_k F_N$, $\mu_k =$ **coefficient of kinetic friction**

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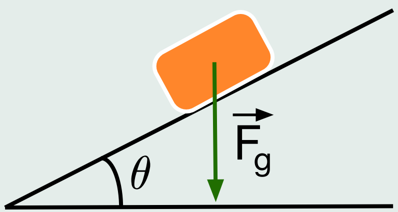
An object is placed on an inclined plane of angle θ. The coefficient of static friction between at the contact surface is μ_s. For which values of θ will the object stay on the plane.



$A)$ For all values of θ.

$B)$ There is no such value of θ.

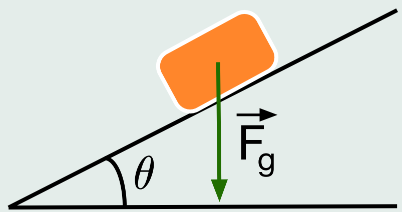
$C)$ For $\tan\theta \leq \mu_s$.

$D)$ For $\sin\theta \leq \mu_s$.

$E)$ For $\tan\theta > \mu_s$.

Answer

An object is placed on an inclined plane of angle θ. The coefficient of static friction between at the contact surface is μ_s. For which values of θ will the object stay on the plane.



$A)$ For all values of θ.

$B)$ There is no such value of θ.

$C)$ For $\tan\theta \le \mu_s$.

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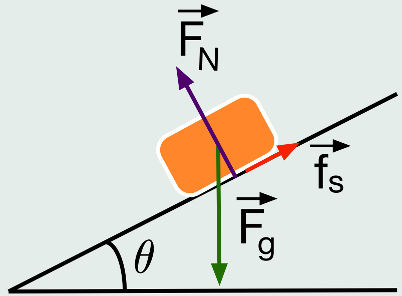

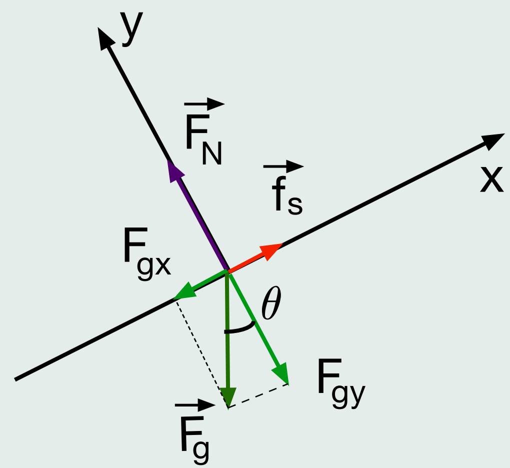

The object will stay on the plane if

$$F_{gx} = f_s$$

$$F_{gx} = mg\sin\theta \qquad f_s \leq (f_s)_{max} = \mu_s F_N$$

$$F_N = -F_{gy} = mg\cos\theta$$

$$mg\,\sin\theta \leq \mu_s mg\,\cos\theta \;\Rightarrow\; \tan\theta \leq \mu_s.$$

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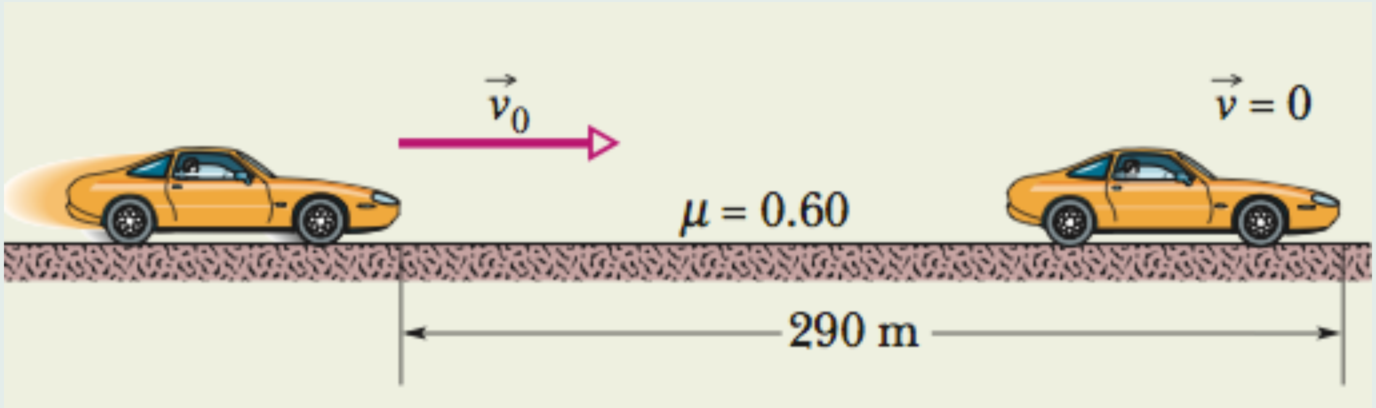
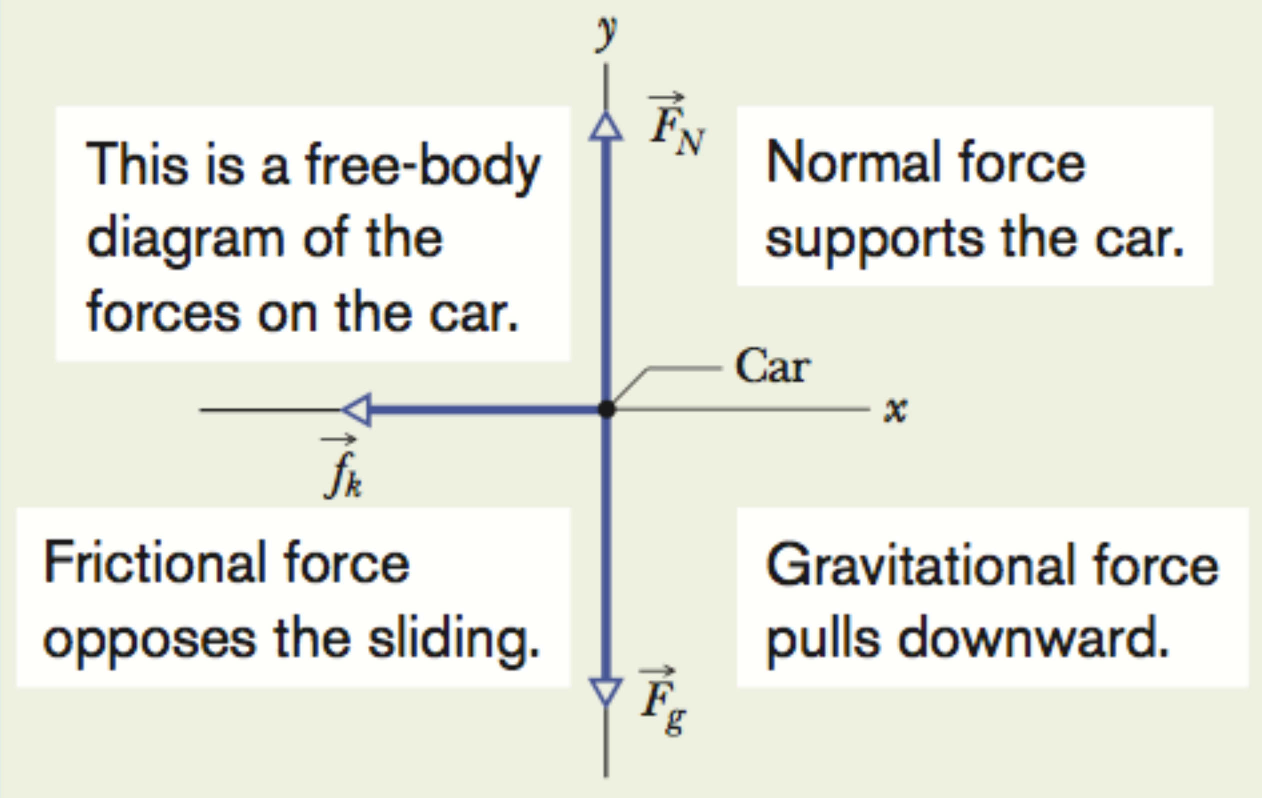
- **Example:** emergency braking



A car slides 290 m on pavement with wheels locked. Assuming $\mu_k = 0.6$ and constant acceleration, what is v_0?



Newton's 2nd law:

$$\vec{F}_{\text{net}} = m\vec{a} = m a_x \widehat{i} \qquad \text{(no vertical motion)}$$

$$x-\text{axis}: \;\; m a_x = -\mu_k F_N \qquad y-\text{axis}: \;\; 0 = F_N - mg$$

$$x-\text{axis}:\;\; ma_x = -\mu_k F_N \qquad\qquad y-\text{axis}:\;\; 0 = F_N - mg$$

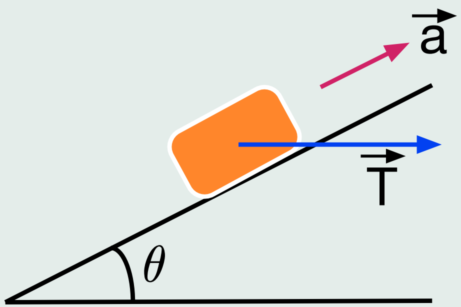
$$a_x = -\mu_k g$$

Constant acceleration model:

$$v^2 = v_0^2 - 2\mu_k g(x - x_0)$$

$$v = 0 \;\;\Rightarrow\;\; v_0^2 = 2\mu_k g(x - x_0) = 58\,\mathrm{m/s} = 210\,\mathrm{km/h}.$$

- **Example:**

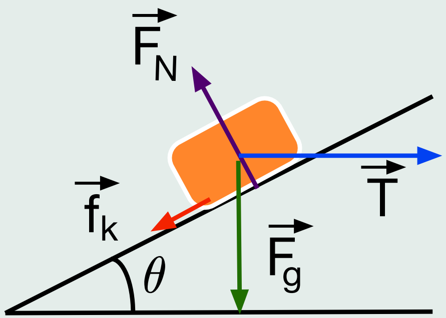


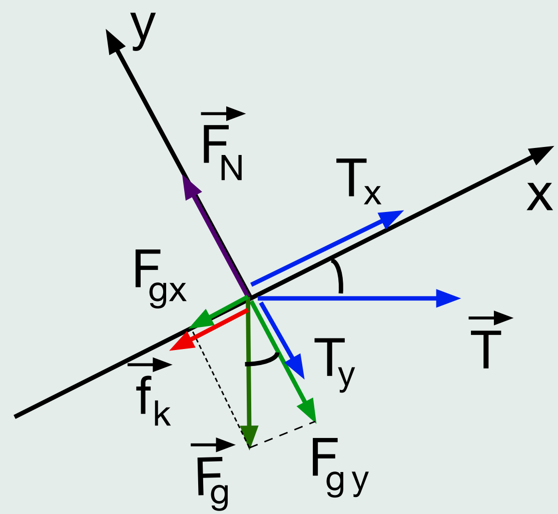
A horizontal tension force $\vec{T}$ is appplied to an object of mass m on an inclined plane.

The object moves upwards along the plane with constant acceleration $\vec{a}$.

Find the kinetic friction coefficient μ_k between the object and the plane.

For which values of T, a is this motion possible?



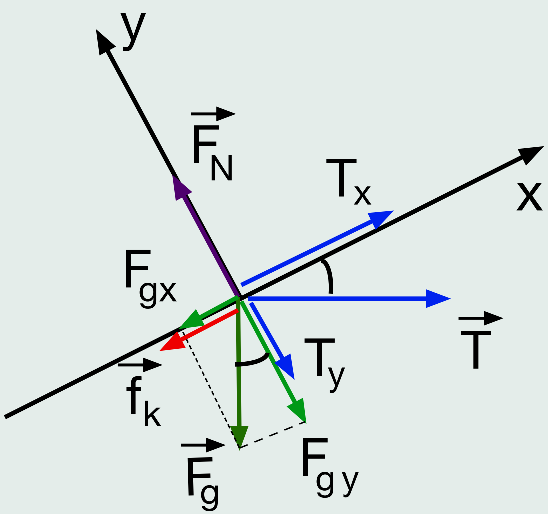


Newton's 2nd law:

$$\vec{F}_{\text{net}} = m\vec{a} = ma\widehat{i} \qquad \vec{F}_{\text{net}} = \vec{T} + \vec{F}_g + \vec{F}_N + \vec{f}_k$$

$$(F_{\text{net}})_x = T\cos\theta - mg\sin\theta - f_k$$

$$(F_{\text{net}})_y = -T\sin\theta - mg\cos\theta + F_N$$



$$(F_{\text{net}})_x = ma \qquad (F_{\text{net}})_y = 0$$

$$(F_{\text{net}})_x = T\cos\theta - mg\sin\theta - f_k$$

$$(F_{\text{net}})_y = -T\sin\theta - mg\cos\theta + F_N$$

$$f_k = T\cos\theta - mg\sin\theta - ma, \qquad f_k = \mu_k F_N$$

$$F_N = T\sin\theta + mg\cos\theta$$

$$\mu_k = \frac{T\cos\theta - mg\sin\theta - ma}{T\sin\theta + mg\cos\theta}$$

For which values of T, a is the motion possible?

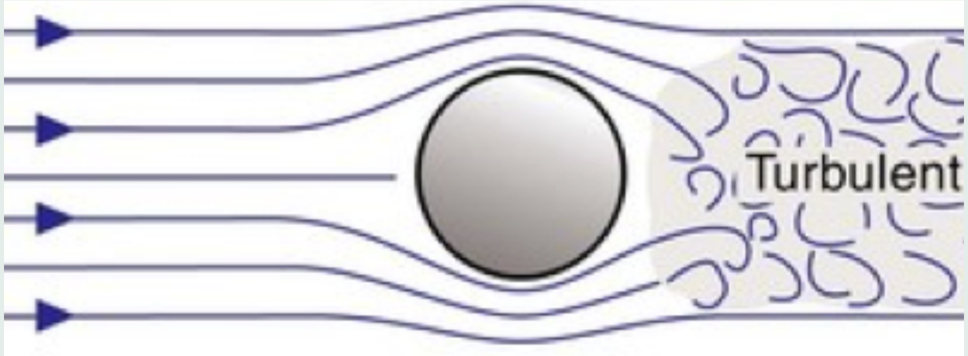
$$\mu_k = \frac{T\cos\theta - mg\sin\theta - ma}{T\sin\theta + mg\cos\theta} \geq 0$$

$$T\cos\theta \geq m(g\sin\theta + a)$$

- # Drag force and terminal speed

Drag force:

- force caused by relative motion of an object and a fluid
- opposed the relative motion and points in the direction the fluid flows relative to the object

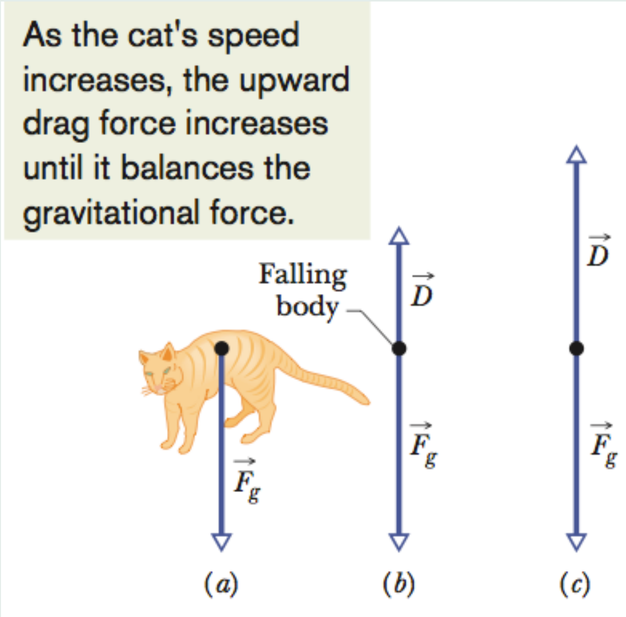


For a fast blunt object moving through air such that the flow becomes turbulent

$$D = \frac{1}{2} C \rho A v^2$$

- A = effective crossection: area of crossection $\perp \vec{v}$
- C = drag coefficient
- ρ = air density

- **Terminal velocity:**



Body falling from rest through air:

The drag force increases gradually until it balances the gravitational force.

The body reaches terminal velocity.

$$\vec{D} + \vec{F}_g = 0$$

$$\frac{1}{2} C A \rho v_y^2 - mg = 0 \;\Rightarrow\; v_y = -\sqrt{\frac{2mg}{C\rho A}}$$

i-Clicker

Theoretically, how long does it take to reach terminal velocity?

$(A)\ \Delta t = \sqrt{\frac{2m}{gC\rho A}}$

$(B)\ \Delta t = 0$

(C) Infinite amount of time.

(D) None of the above.

Answer

Theoretically, how long does it take to reach terminal velocity?

(A) $\Delta t = \sqrt{\frac{2m}{gC\rho A}}$

(B) $\Delta t = 0$

(C) Infinite amount of time.

(D) None of the above.

Why?

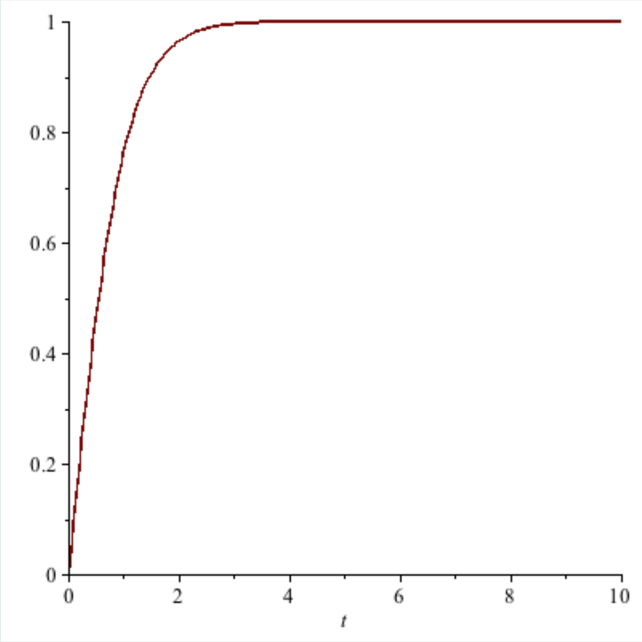
$$\vec{F}_{\text{net}} = m\vec{a} \qquad \vec{F}_{\text{net}} = \vec{D} + \vec{F}_g$$

$$\left(F_{\text{net}}\right)_y = \frac{1}{2} C A \rho v_y^2 - mg$$

$$\frac{dv_y}{dt} = \kappa v_y^2 - mg, \qquad \kappa = \frac{1}{2} C A \rho$$

$$\Downarrow$$

$$v_y = -\sqrt{\frac{mg}{\kappa}} tanh\left(\sqrt{mg\kappa} t\right) = -\sqrt{\frac{mg}{\kappa}} \frac{e^{\sqrt{mg\kappa} t} - e^{-\sqrt{mg\kappa} t}}{e^{\sqrt{mg\kappa} t} + e^{-\sqrt{mg\kappa} t}}$$



Terminal velocity:

$$\lim_{t\to\infty} v_y = -\sqrt{\frac{mg}{\kappa}} = -\sqrt{\frac{2mg}{C\rho A}}$$

$$\lim_{t\to\infty} a_y = \lim_{t\to\infty} \frac{dv_y}{dt} = 0$$

Some Terminal Speeds in Air

Object	Terminal Speed (m/s)	95% Distance[a] (m)
Shot (from shot put)	145	2500
Sky diver (typical)	60	430
Baseball	42	210
Tennis ball	31	115
Basketball	20	47
Ping-Pong ball	9	10
Raindrop (radius = 1.5 mm)	7	6
Parachutist (typical)	5	3

[a]This is the distance through which the body must fall from rest to reach 95% of its terminal speed.

Source: Adapted from Peter J. Brancazio, *Sport Science*, 1984, Simon & Schuster, New York.

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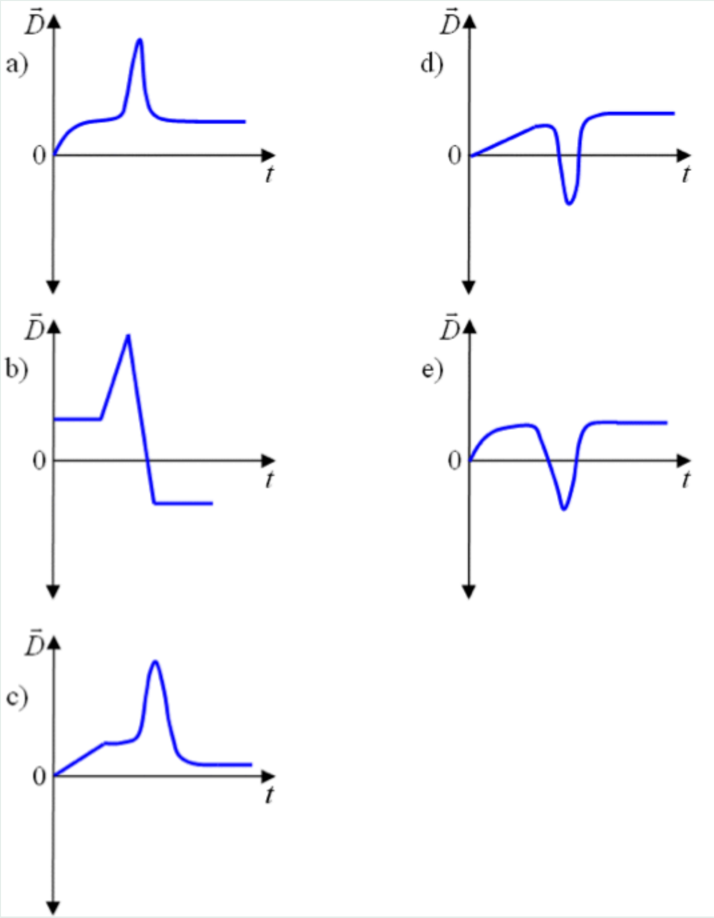
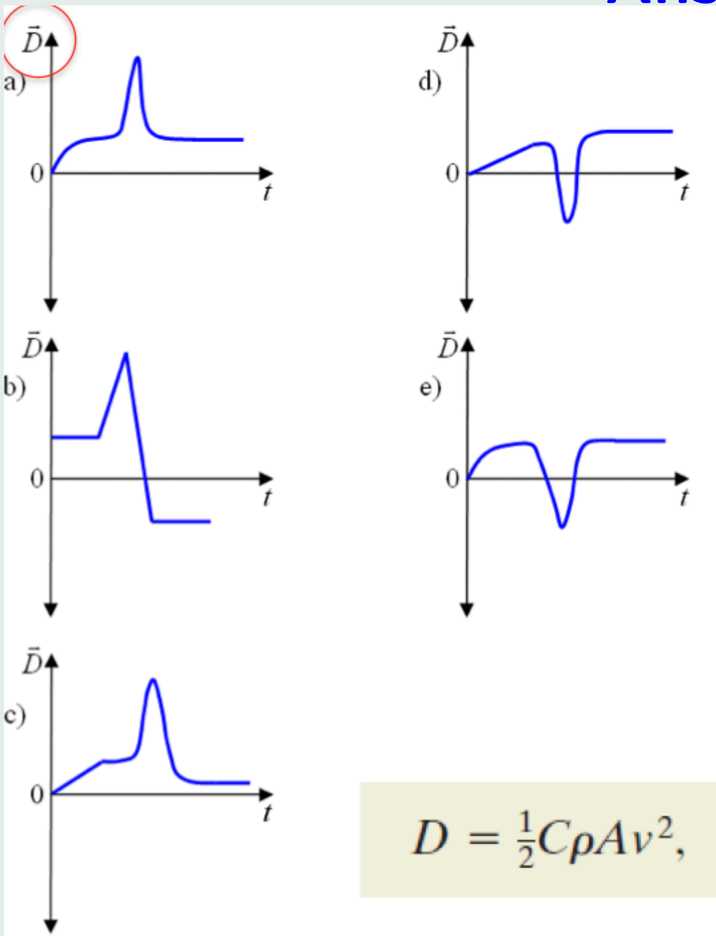


A sky diver jumps from a flying airplane and falls for several seconds before she reaches terminal velocity. She then opens her parachute, reaches a new terminal velocity, and continues her descent to the ground. Which one of the following graphs of the drag force versus time best represents this situation?

Answer



$$D = \frac{1}{2} C \rho A v^2,$$

A sky diver jumps from a flying airplane and falls for several seconds before she reaches terminal velocity. She then opens her parachute, reaches a new terminal velocity, and continues her descent to the ground. Which one of the following graphs of the drag force versus time best represents this situation?

Before opening the parachute terminal velocity is reached when

$$\vec{D} + \vec{F}_g = 0 \qquad D = F_g$$

After opening the parachute terminal velocity is again reached when

$$\vec{D} + \vec{F}_g = 0 \qquad D = F_g$$

A sufficiently long time after opening the magnitude of the drag force must equal its value before opening. At the same time it should spike upwards during opening.