

Rutgers University
Department of Physics & Astronomy

01:750:271 Honors Physics I
Fall 2015

Lecture 7

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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

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Gradebook

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

The screenshot shows a web browser window titled "GradeBook". The address bar contains the URL <https://gbook.physics.rutgers.edu/gbook/student.pl?271&semester=fall2014>. Below the address bar is a search bar with the Google logo and a search button. A navigation bar contains links to Google, Apple, Mathscinet, Wikipedia, YouTube, News (1,416), and Popular. The main header features the text "GERS" on the left, "Honors Physics 271 - Fall2014" in the center, and "GRA" on the right. The body of the page has a yellow background and contains the text "Please enter your Rutgers NetID and Password to login" in purple. Below this text are two input fields: "Rutgers NetID:" followed by a text box, and "Password:" followed by a text box. A "Login" button is located to the right of the password field.

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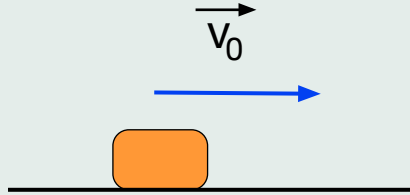
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6. Forces and Motion II

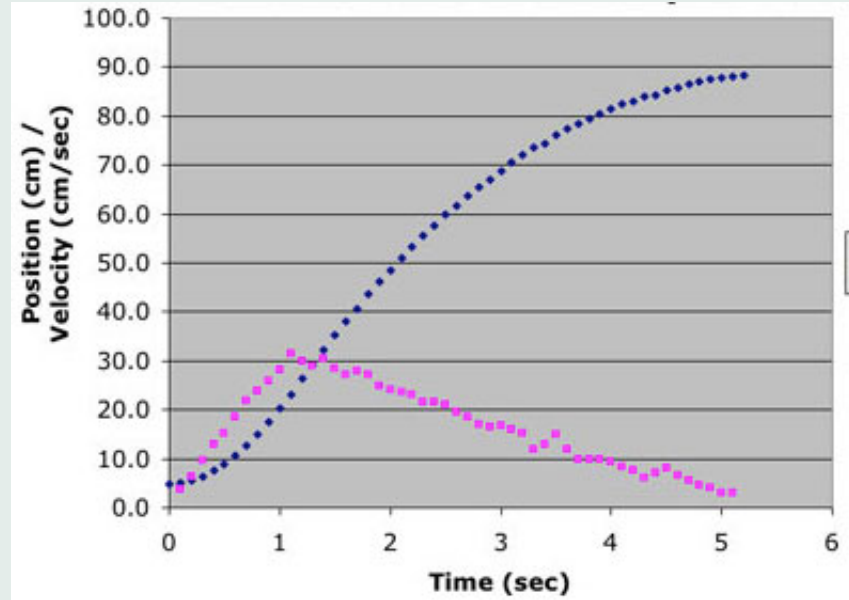
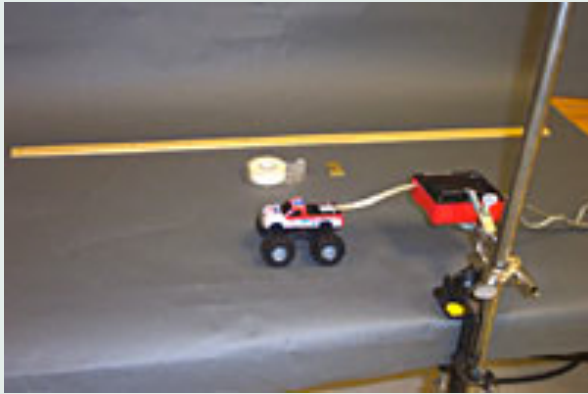
- Friction



- 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?

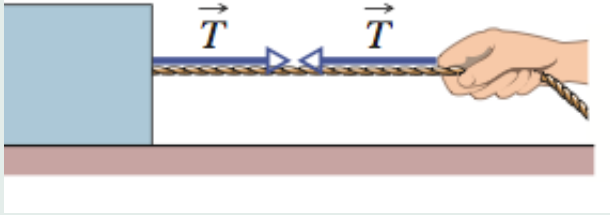
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- **Experiment:** a toy truck is quickly accelerated to some velocity $\vec{v}_0$ and then released.



It stops in finite time; x vs time $\sim$ parabola
 v_x vs time $\sim$ linear once it starts decelerating $\Rightarrow$
constant negative acceleration

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



Static



In motion

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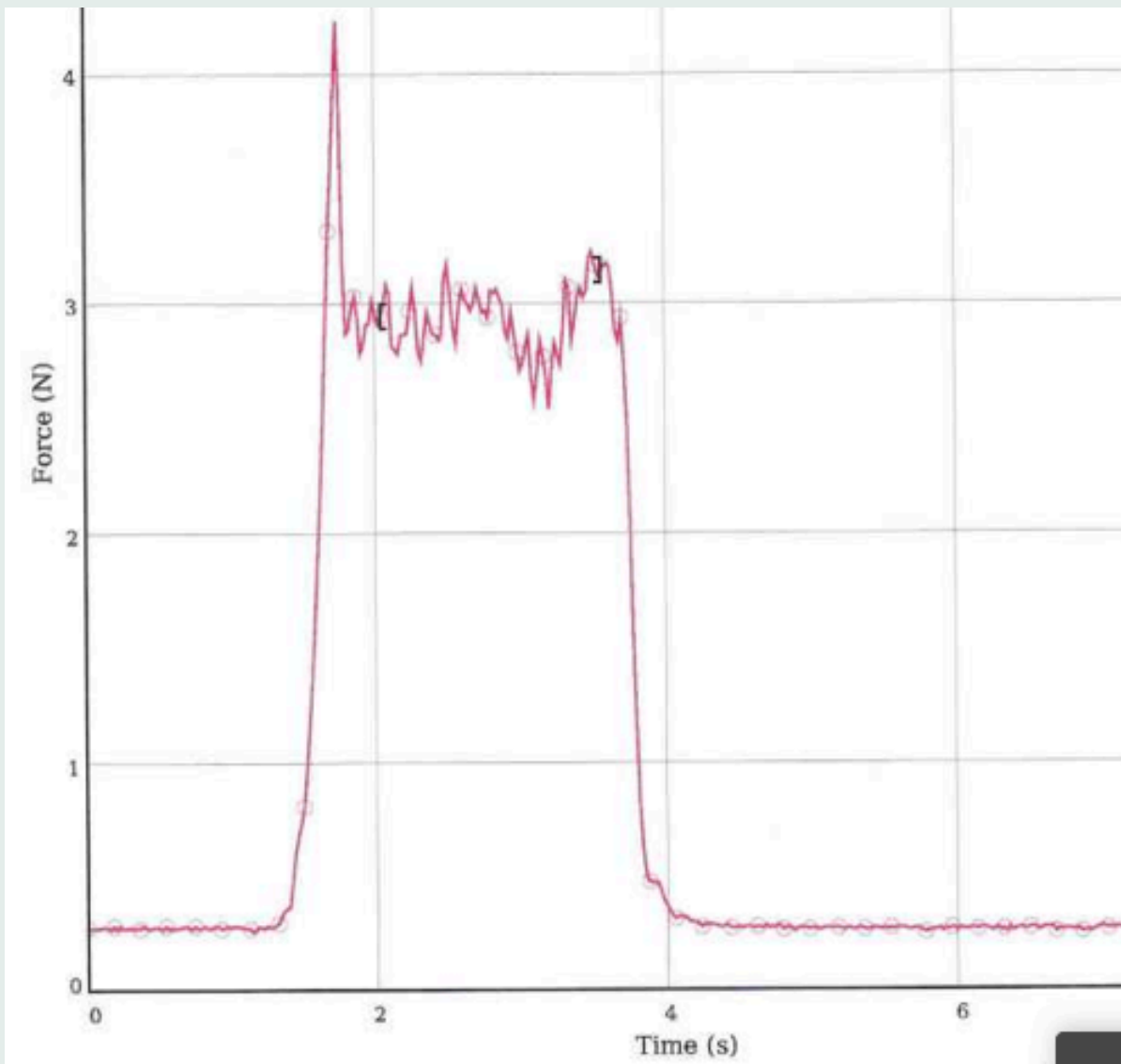
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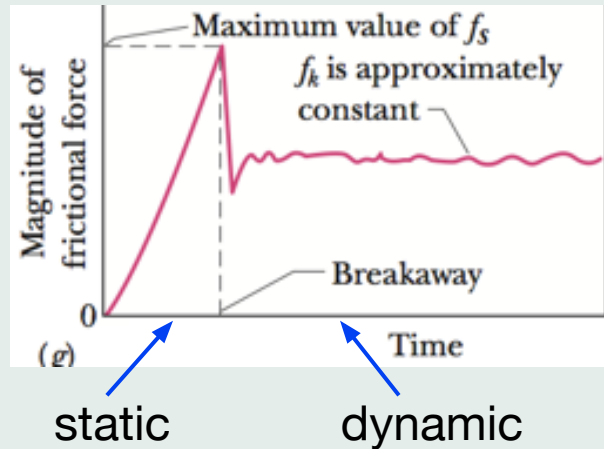
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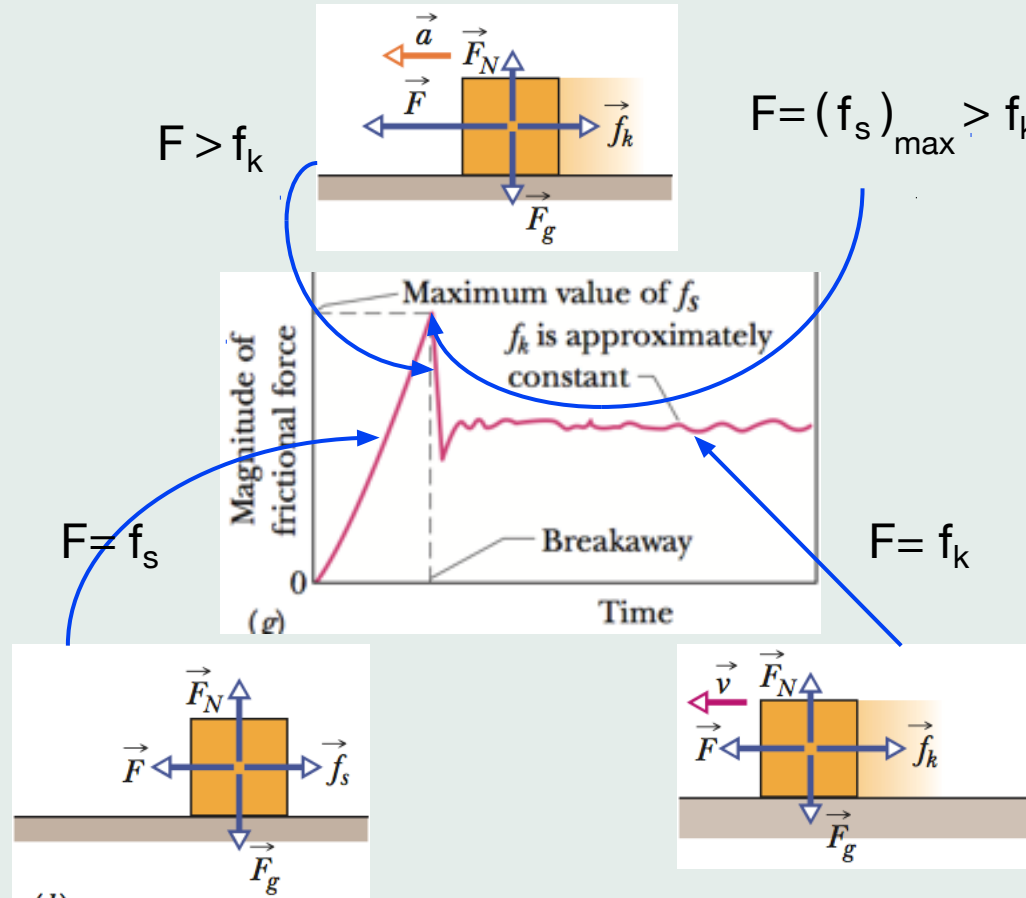
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- **Static** friction $\vec{f}_s$ acts when no **relative motion** between object and contact surface.
- The magnitude f_s increases as the applied force increases until it reaches a maximum value $(f_s)_{\max}$.
- **Kinetic** friction $\vec{f}_k$ acts when there is **relative motion** between object and contact surface.
- Usually $f_k < (f_s)_{\max}$.

Static Dynamic Transition



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- **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 :

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

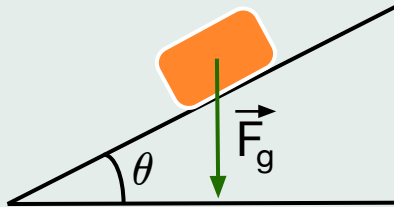
where $\mu_s =$ **coefficient of static friction**. When $F \geq (f_s)_{\max}$ the object begins to slide.

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

$$f_k = \mu_k F_N, \quad \mu_k = \text{coefficient of kinetic friction}$$

i-Clicker

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.

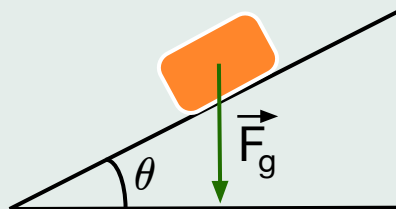


- A) For all values of θ .
- B) There is no such value of θ .
- C) For $\tan \theta \leq \mu_s$.
- D) For $\sin \theta \leq \mu_s$.
- E) For $\tan \theta > \mu_s$.

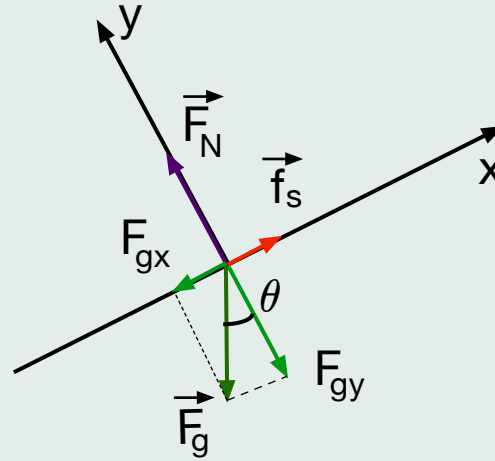
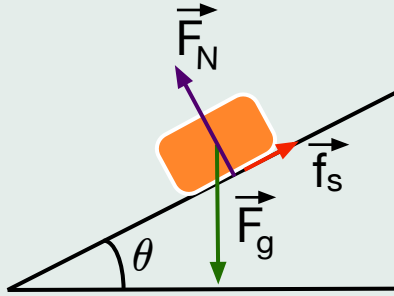
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Answer

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 $\tan \theta \leq \mu_s$.
- D) For $\sin \theta \leq \mu_s$.
- E) For $\tan \theta > \mu_s$.



The object will stay on the plane if

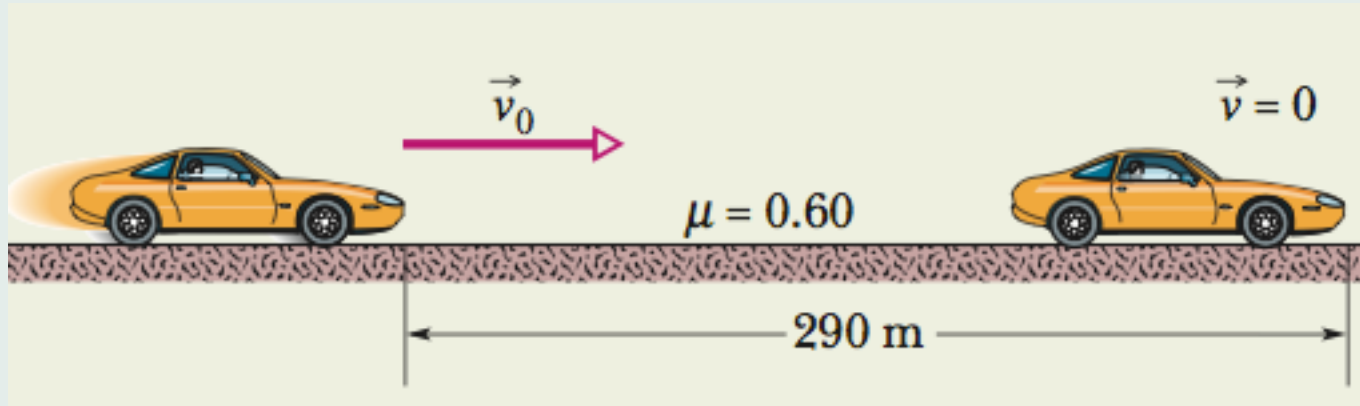
$$F_{gx} = f_s$$

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

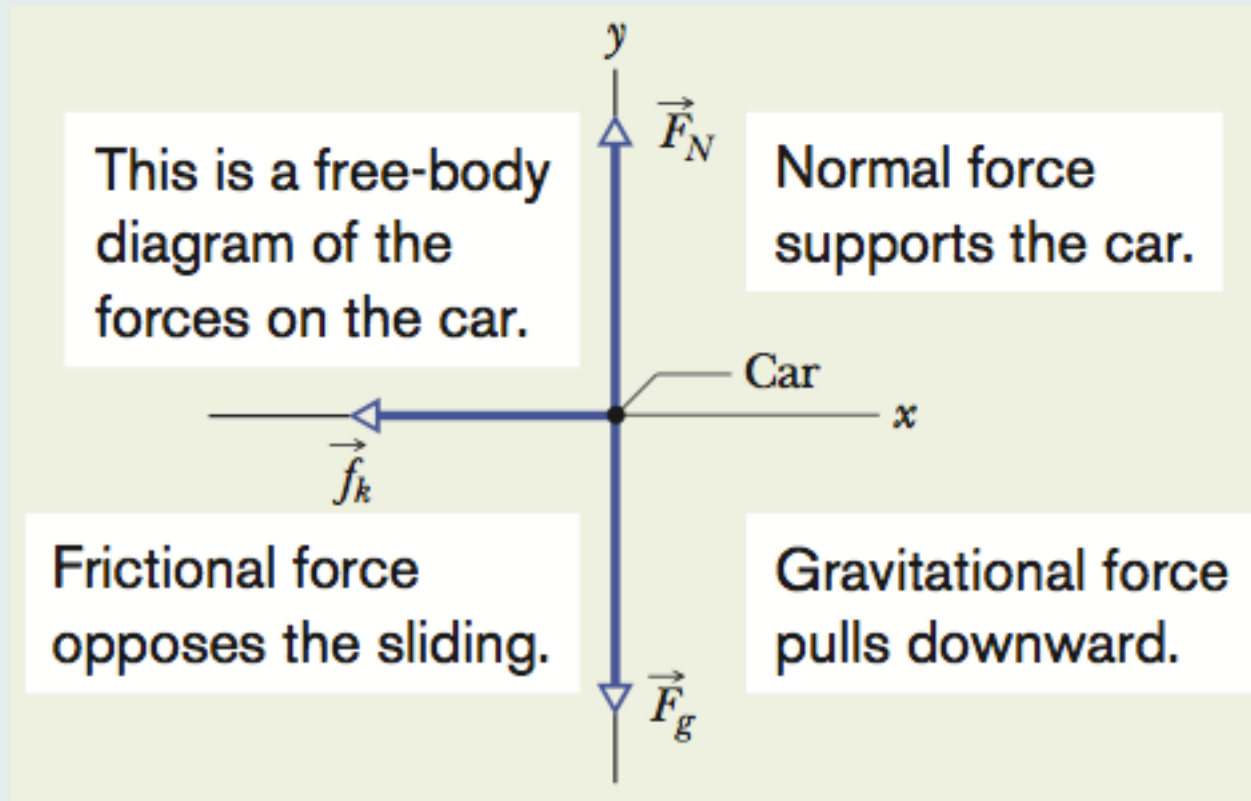
$$F_N = -F_{gy} = mg \cos \theta$$

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

- **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:

$$\vec{F}_{\text{net}} = m\vec{a} = ma_x\hat{i} \quad (\text{no vertical motion})$$

$$x - \text{axis} : ma_x = -\mu_k F_N$$

$$y - \text{axis} : 0 = F_N - mg$$

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

$$a_x = -\mu_k g$$

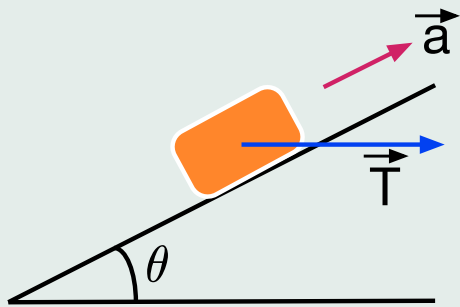
Constant acceleration model:

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

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

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- **Example:**

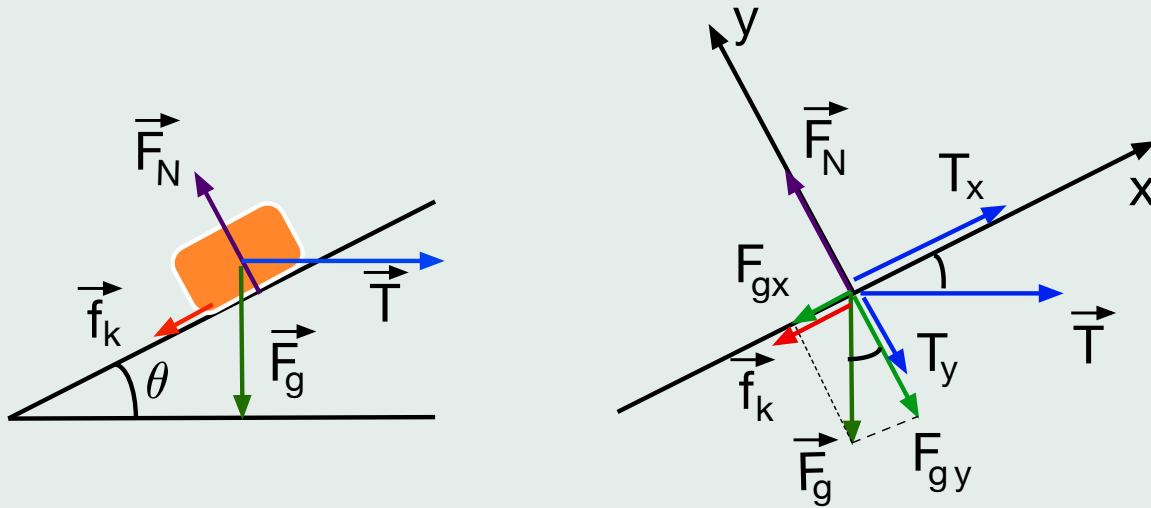


A horizontal tension force $\vec{T}$ is applied to an object of mass m on an inclined plane.

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?

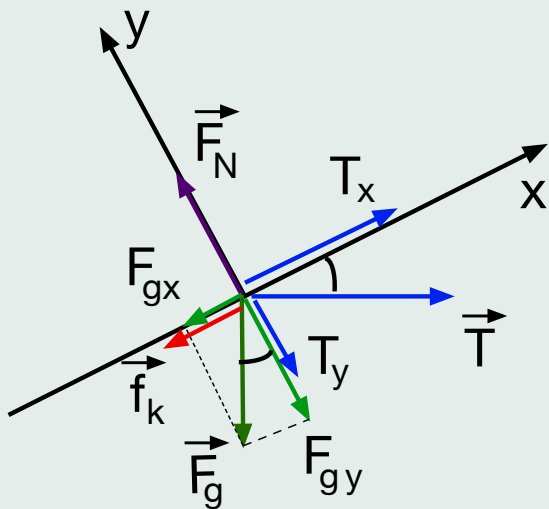


Newton's 2nd law:

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

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

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



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

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

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

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

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

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

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

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

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

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- **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

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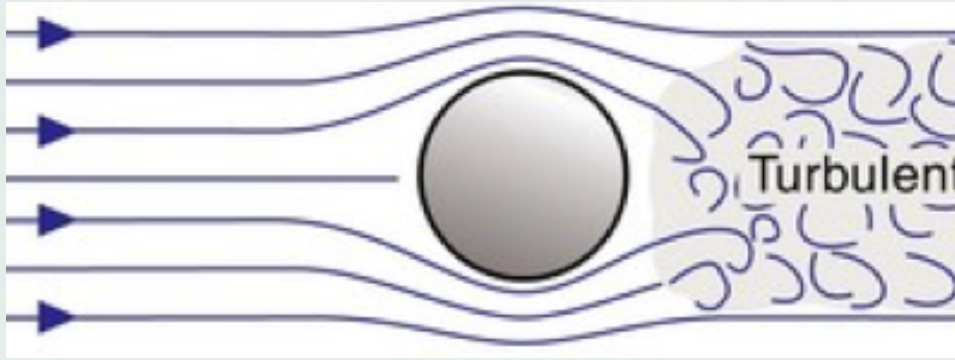
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For a fast blunt object moving through air such that the flow becomes **turbulent**

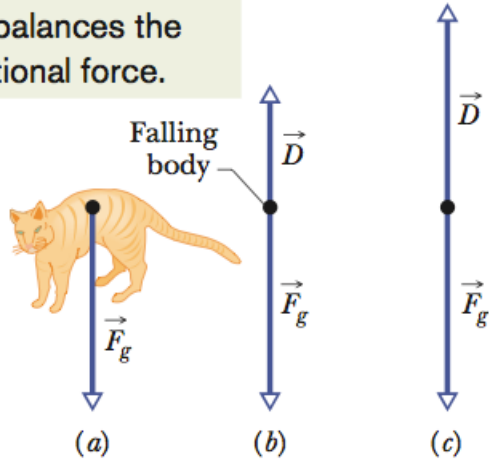
$$D = \frac{1}{2}C\rho Av^2$$

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

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● Terminal velocity:

As the cat's speed increases, the upward drag force increases until it balances the gravitational force.



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.

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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?

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

$$(F_{\text{net}})_y = \frac{1}{2}CA\rho v_y^2 - mg$$

$$\frac{dv_y}{dt} = \kappa v_y^2 - mg, \quad \kappa = \frac{1}{2}CA\rho$$

↓

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

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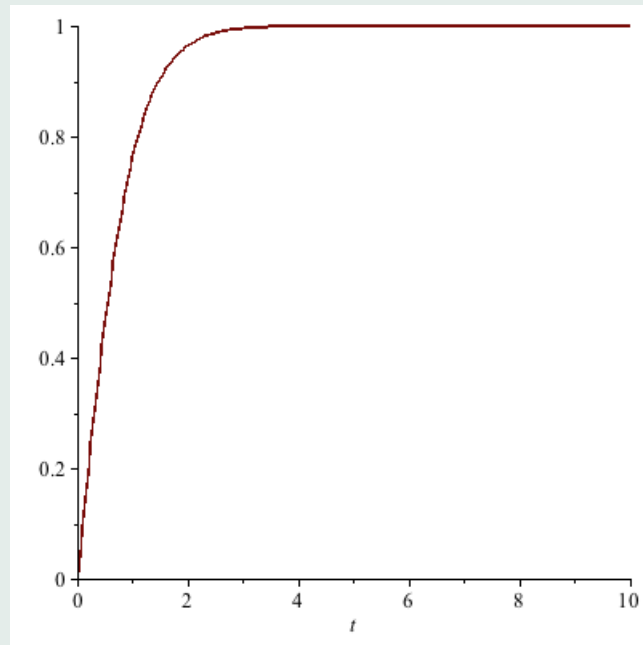
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Terminal velocity:

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

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

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Some Terminal Speeds in Air

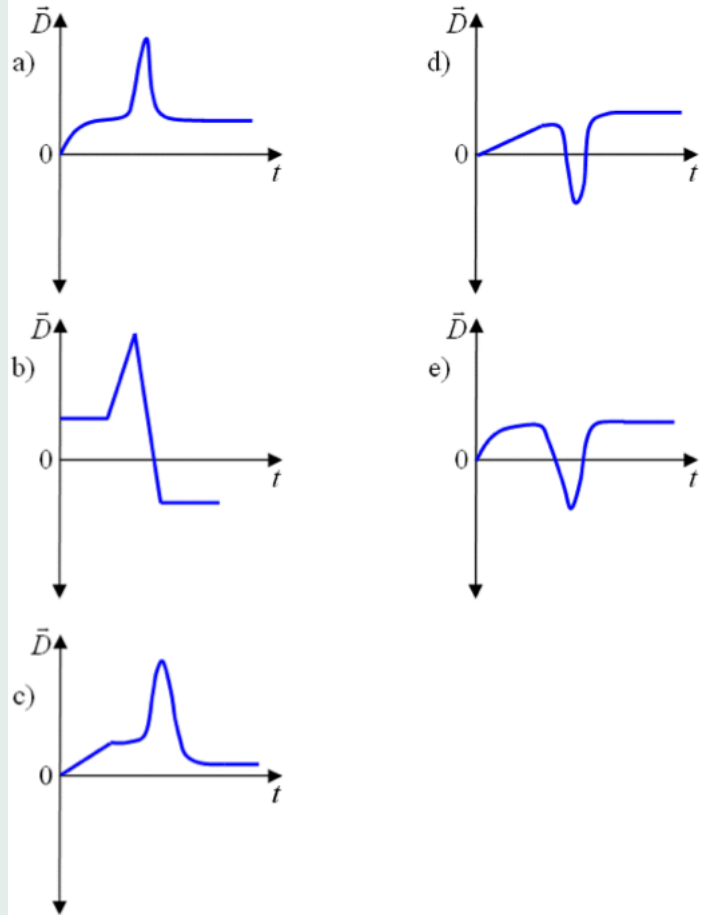
Object	Terminal Speed (m/s)	95% Distance ^a (m)
Shot (from shot put)	145	2500
Sky diver (typical)	60	430
Baseball	42	210
Tennis ball	31	115
Basketball	20	47
Ping-Pong ball	9	10
Raindrop (radius = 1.5 mm)	7	6
Parachutist (typical)	5	3

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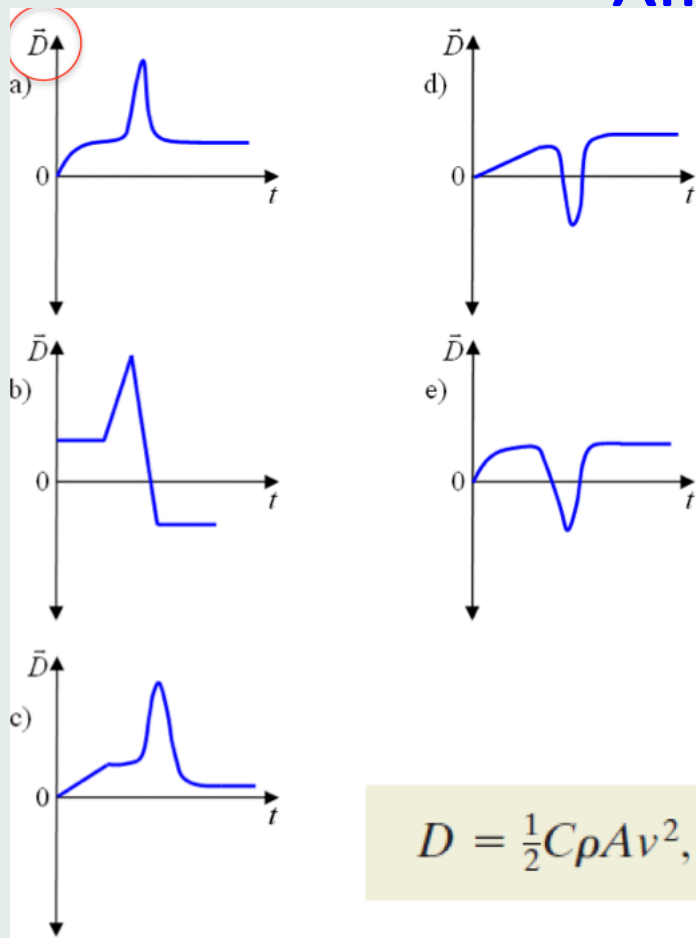
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A sky diver jumps from a flying airplane and falls for several seconds before she reaches terminal velocity. She then opens her parachute, reaches a new terminal velocity, and continues her descent to the ground. Which one of the following graphs of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

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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

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

After opening the parachute terminal velocity is again reached when

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

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.

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