Physics 1

Lecture 11

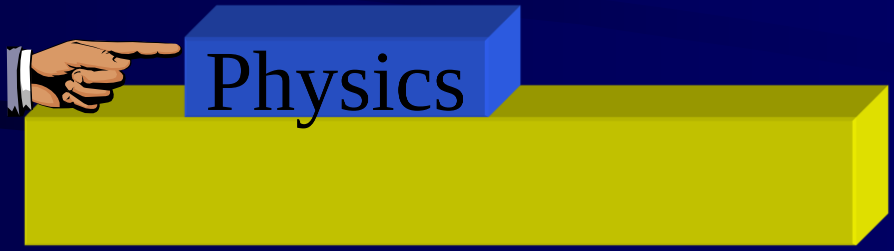
Sahraei

Physics Department,
Razi University

http://www.razi.ac.ir/sahraei

Forces of Friction

- When an object is in motion on a surface or through a viscous medium, there will be a resistance to the motion.



  – **This is due to the interactions between the object and its environment.**

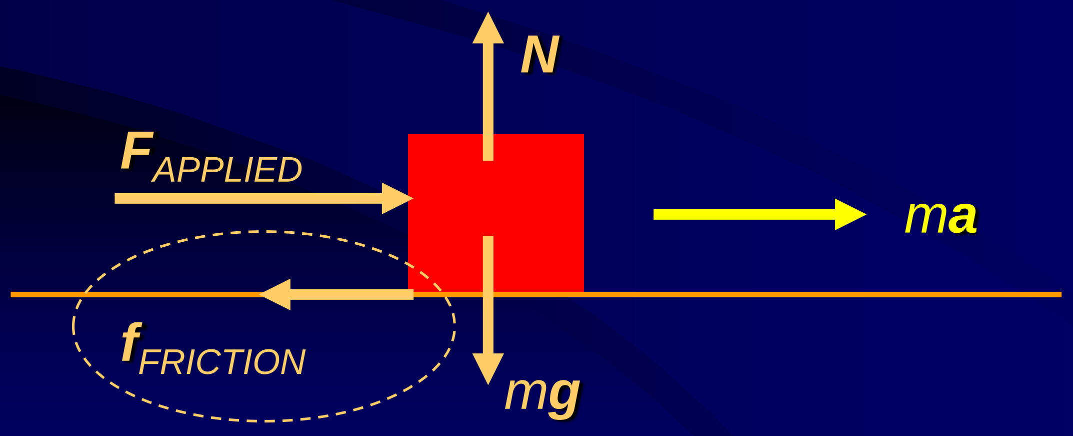
- This resistance is called **friction.**

Friction

It opposes relative motion!

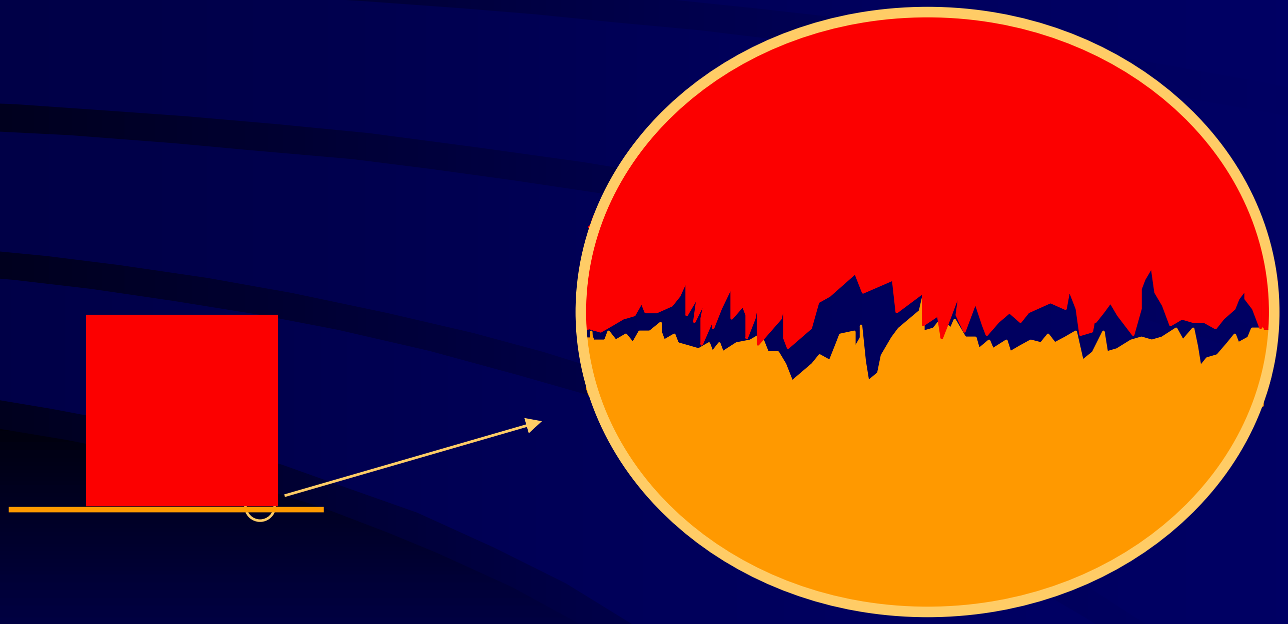
Parallel to surface.

Perpendicular to *N*ormal force.



Surface Friction...

- Friction is caused by the "microscopic" interactions between the two surfaces:



Friction

- We will initially look at two kinds of friction:
  - **Static Friction**
  - **Kinetic Friction**
- Given the names, you might guess that the 1st case has to do with when an object is not moving, and the 2nd case with when a body is in motion

Static Friction

- The magnitude of the static friction force f_s has a maximum value which is given by:

$$f_s \leq \mu_s N \qquad f_{s,max} = \mu_s N$$

where μ_s is the coefficient of static friction and N is the magnitude of the normal force on the body from the surface.

Kinetic Friction

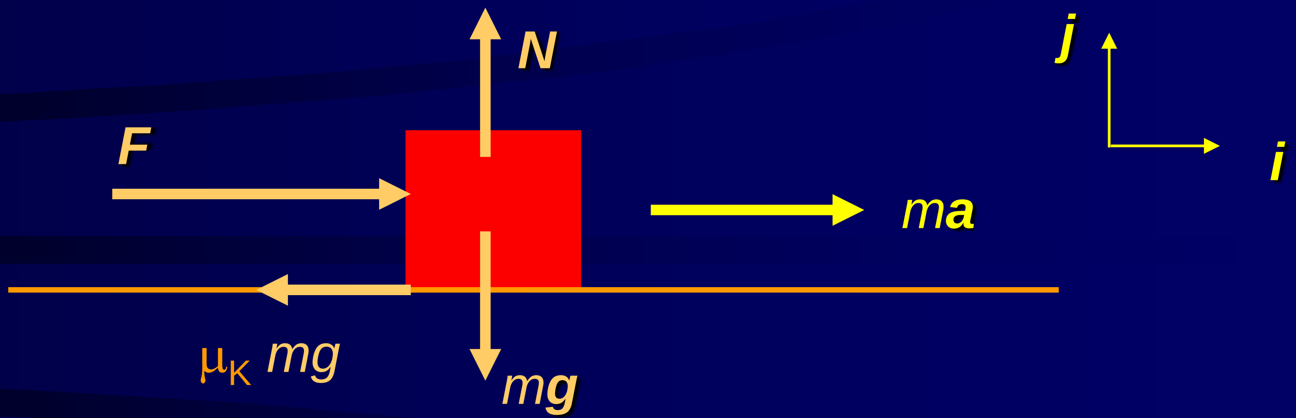
- If the component of the applied force on the object (parallel to the surface) exceeds $f_{s,max}$ then the magnitude of the opposing force decreases rapidly to a value f_k given by:

$$f_k = \mu_k N \qquad \mu_s > \mu_k$$

where μ_k is the coefficient of kinetic friction

The coefficient of friction (μ) depends on the surfaces in Contact.

The coefficients of friction are nearly independent of the area of contact.



Dynamics:

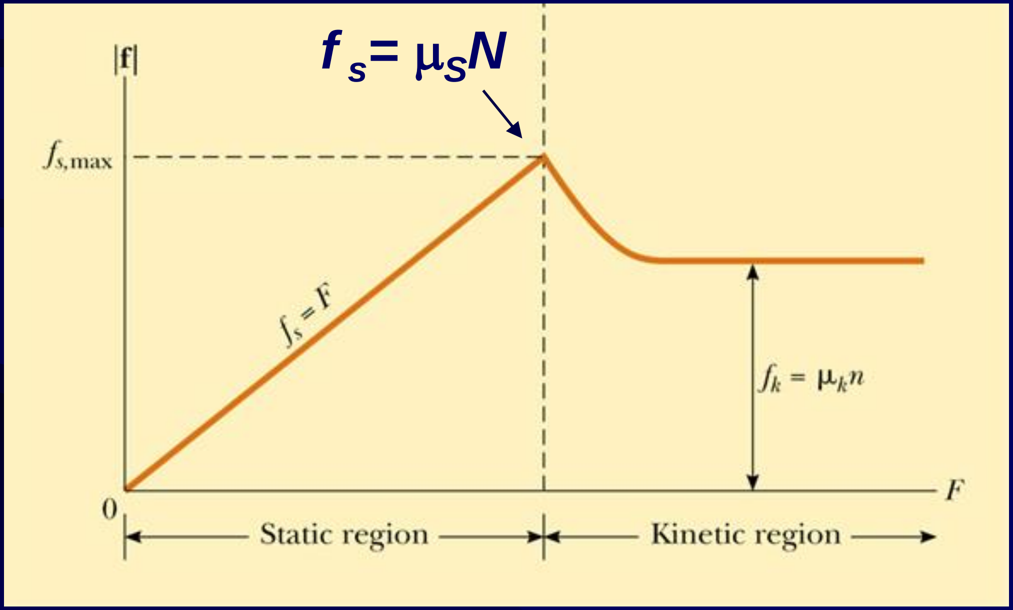
$$x: \quad F - \mu_K N = ma$$

$$y: \quad N = mg$$

$$\text{so} \quad F - \mu_K mg = ma$$

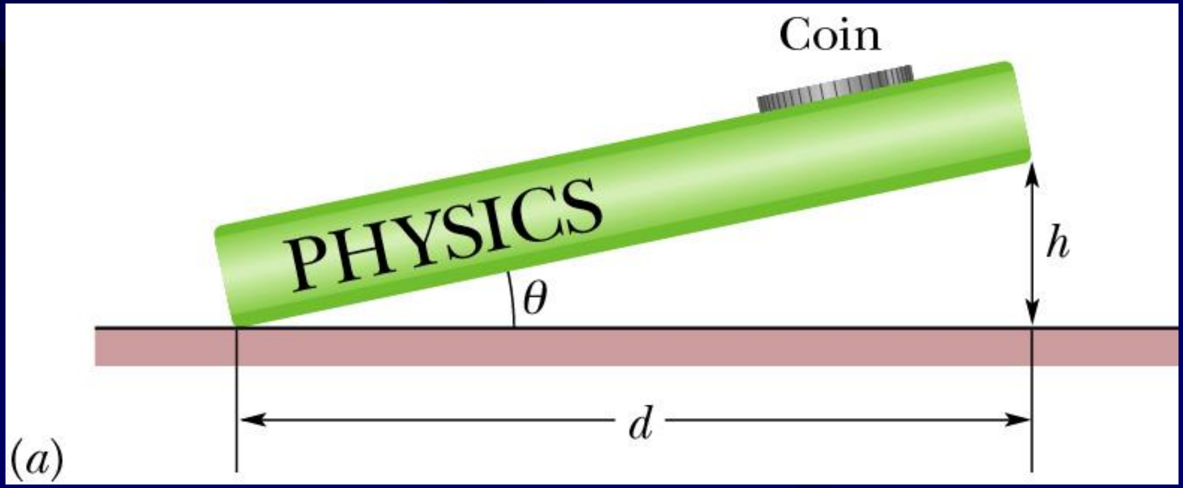
Friction

- Variable magnitude of the friction force as a function of pushing force F summarized in the following graph:



Sample Problem

- At an angle θ of 13º, the coin is on the verge of sliding down the book
- What is the value of the coefficient of static friction μ_s?

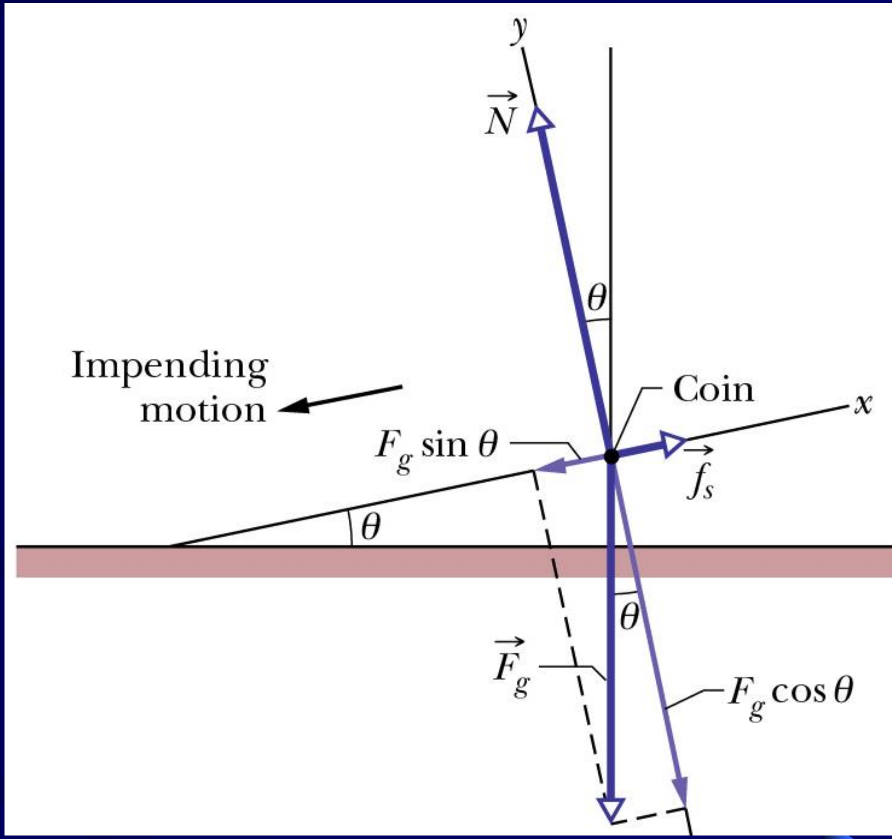


Sample Problem

The free-body diagram shows the two forces acting upon the coin.

$$\sum \vec{F} = 0$$

$$\begin{cases} \sum F_x = f_s - mg\sin\theta = 0 \\ \sum F_y = N - mg\cos\theta = 0 \end{cases}$$

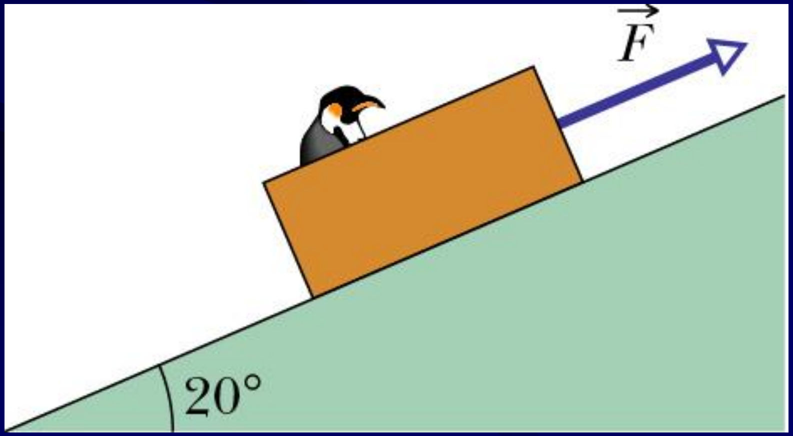


$$\mu_s = \frac{f_s}{N} = \frac{mg\sin\theta_s}{mg\cos\theta_s} = tg\theta_s = tg13^0 = 0.23$$

$$\mu_k = \tan\theta_k, \qquad \theta_k < \theta_s$$

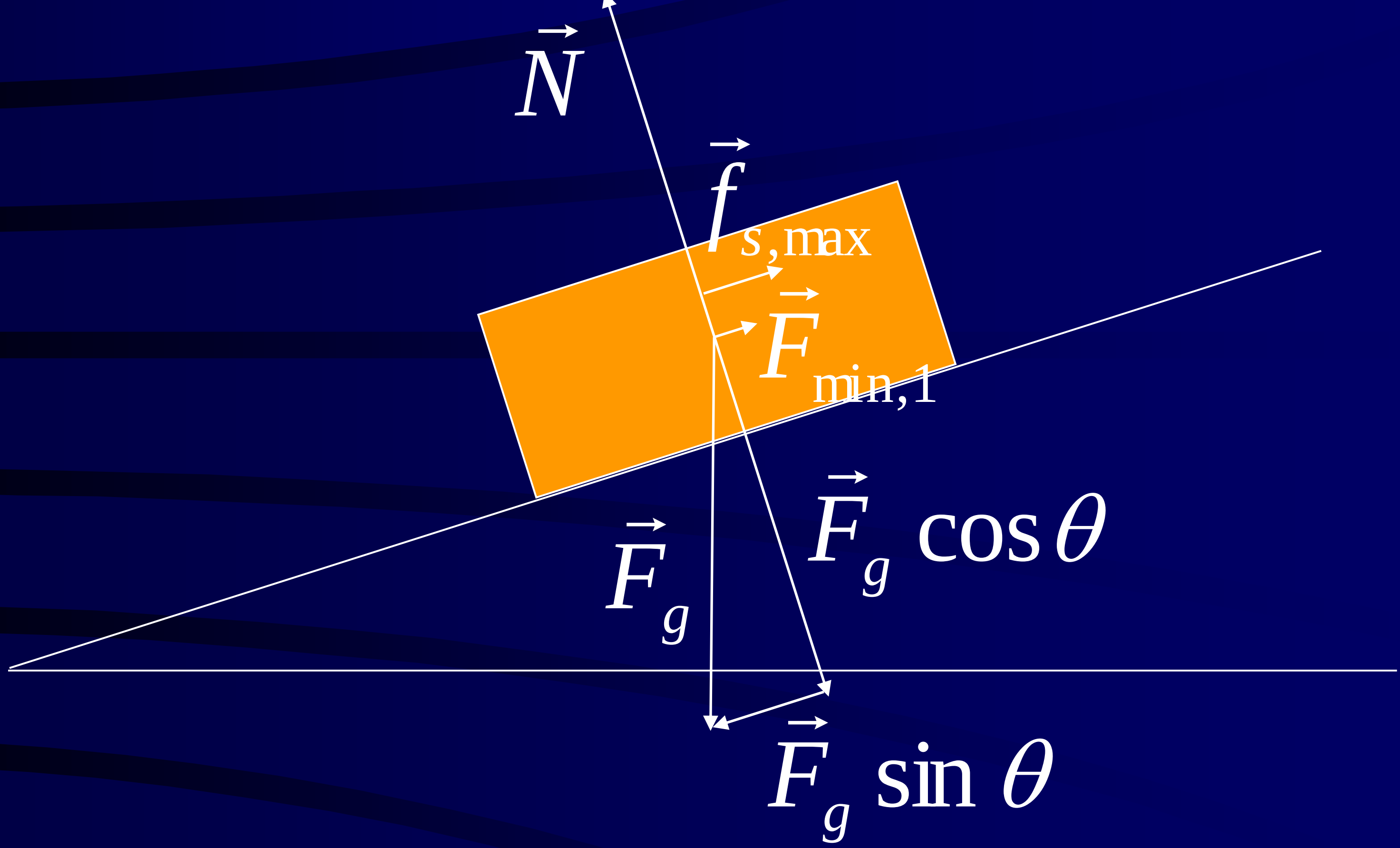
Problem

- $\mu_s = 0.25$; $\mu_k = 0.15$; Sled weighs 80N; $\theta = 20^o$
- What is the minimum F to keep the sled from slipping?
- What is the minimum F to get the sled moving up the plane?
- What value of F is required to keep the sled moving up the plane?



Problem (a)

- In this case, we know that just enough force $F_{\text{min},1}$ is applied pointing uphill to keep the sled from slipping down the hill
- Therefore the frictional force must also be pointing up the hill (helping to hold the sled from slipping) – and that force must be at its maximum static value: $f_{\text{s,max}}$



$$F_{\min,1} - mg\sin\theta + f_{s,\max} = ma = 0$$

$$f_{s,\max} = \mu_s N = \mu_s mg\cos\theta$$

- We end up with (for $\theta = 20^{o}$):

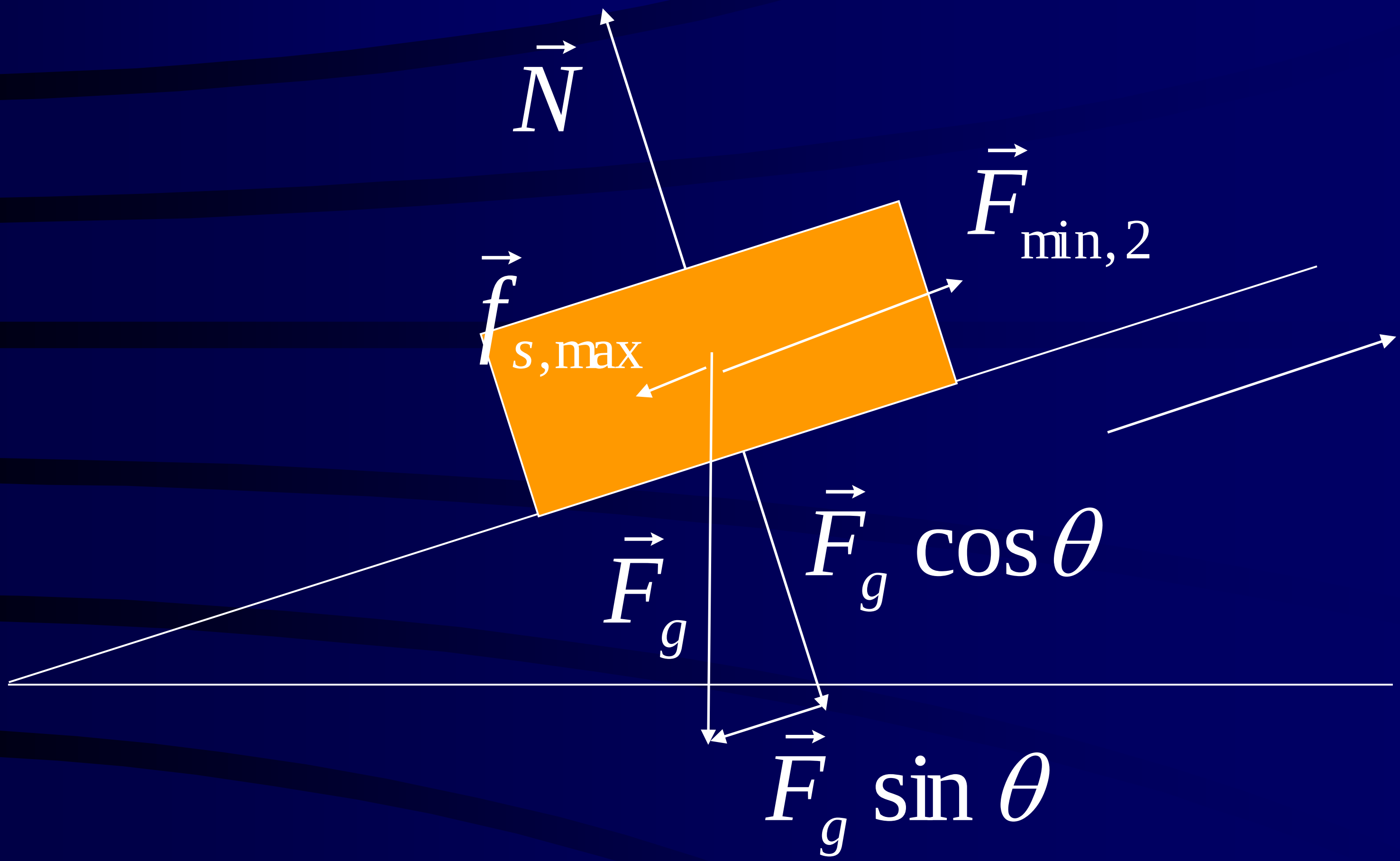
$$F_{\min,1} - mg\sin\theta + \mu_s mg\cos\theta = 0$$

$$F_{\min,1} = mg(\sin\theta - \mu_s\cos\theta) = 8.6\ \mathrm{N}$$

- So we need a minimum force of 8.6 N applied uphill in order to keep the sled from slipping down the hill

Problem (b)

- In this case, we want to know how much force $F_{min,2}$ (pointing uphill) is necessary to just start the sled moving up the hill
- Therefore the frictional force must in this case be pointing down the hill (helping to keep the sled from moving uphill) – and that force must again be at its maximum static value: $f_{s,max}$



$$F_{\min,2} - mg\sin\theta - f_{s,\max} = ma = 0$$

$$f_{s,\max} = \mu_s N = \mu_s mg\cos\theta$$

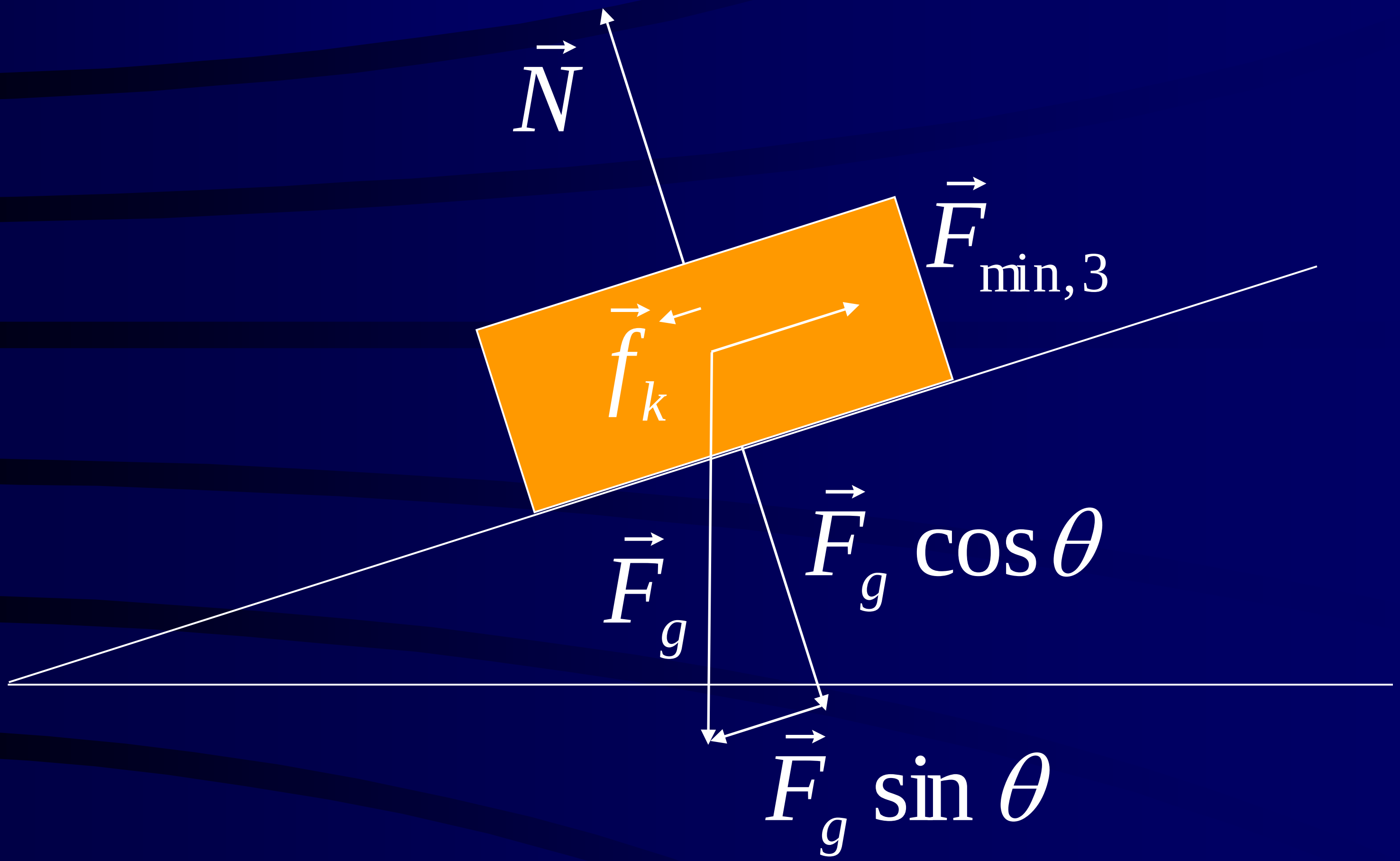
- **We end up with (for θ = 20º):**

$$F_{\min,2} - mg\sin\theta - \mu_s mg\cos\theta = 0$$
$$F_{\min,2} = mg(\sin\theta + \mu_s\cos\theta) = 46\ \mathrm{N}$$

- **So we need a minimum force of 46 N applied uphill in order to start the sled moving up the hill**

Problem (c)

- Finally, having gotten the sled started up the hill, we want to know how much force $F_{\min,3}$ (pointing uphill) is necessary to just keep the sled moving up the hill
- Therefore the frictional force must in this case still be pointing <u>down</u> the hill (working against the sled moving uphill) – but this time the force must be at its kinetic value: f_k



$$F_{\min,3} - Fmg\sin\theta - f_k = ma = 0$$

$$f_k = \mu_k N = \mu_k mg\cos\theta$$

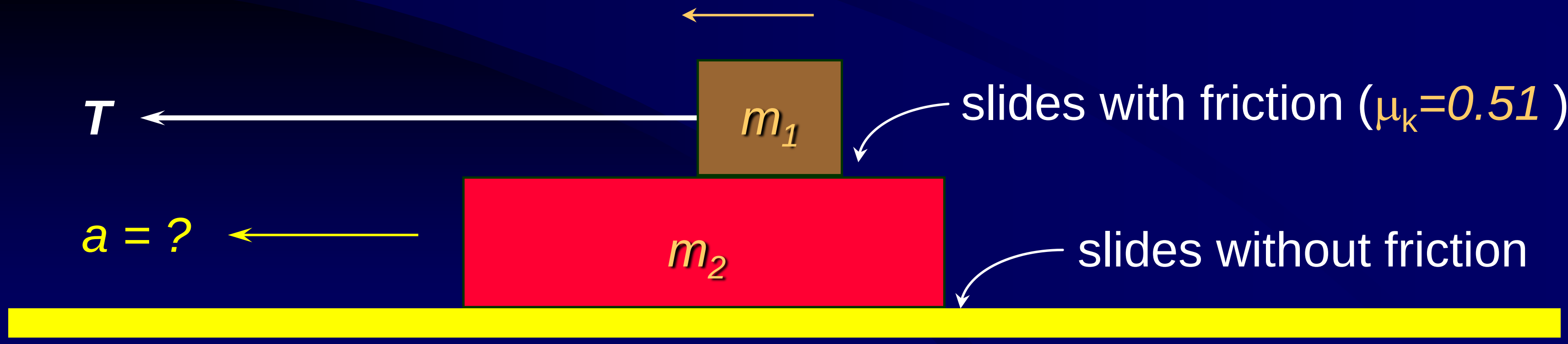
- We end up with (for $\theta = 20^o$):

$$F_{\min,3} - mg\sin\theta - \mu_k Fmg\cos\theta = 0$$

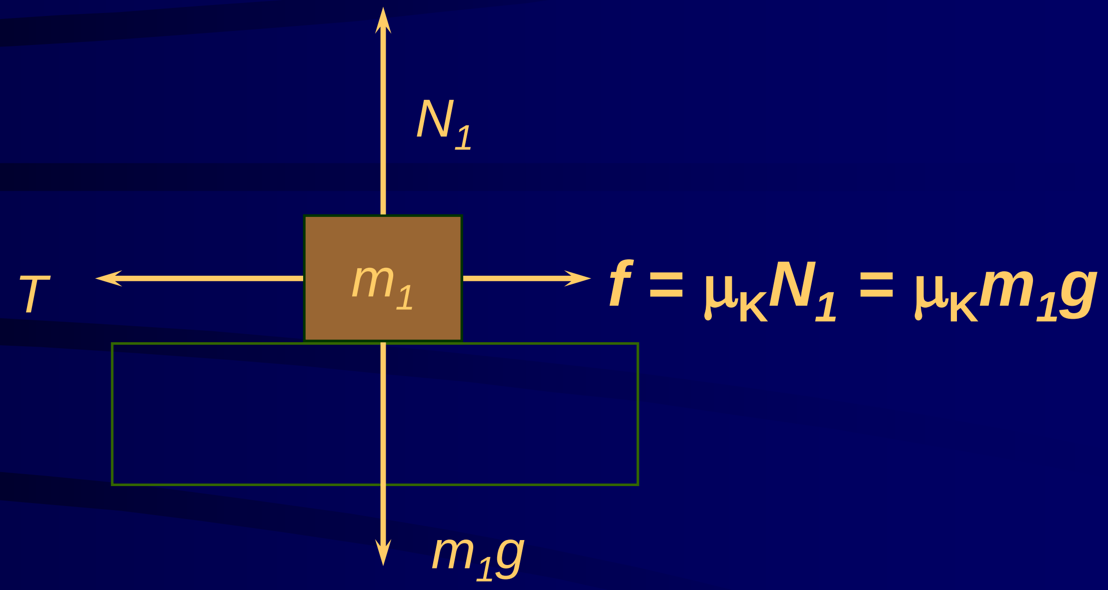
$$F_{\min,3} = Fmg\left(\sin\theta + \mu_k \cos\theta\right) = 39\ \mathrm{N}$$

- So we need a minimum force of 39 N applied uphill in order to <u>keep</u> the sled moving up the hill

- A box of mass $m_1 = 1.5\ kg$ is being pulled by a horizontal string having tension $T = 90\ N$. It slides with friction ($\mu_k = 0.51$) on top of a second box having mass $m_2 = 3\ kg$, which in turn slides on a frictionless floor.
  - What is the acceleration of the second box ?

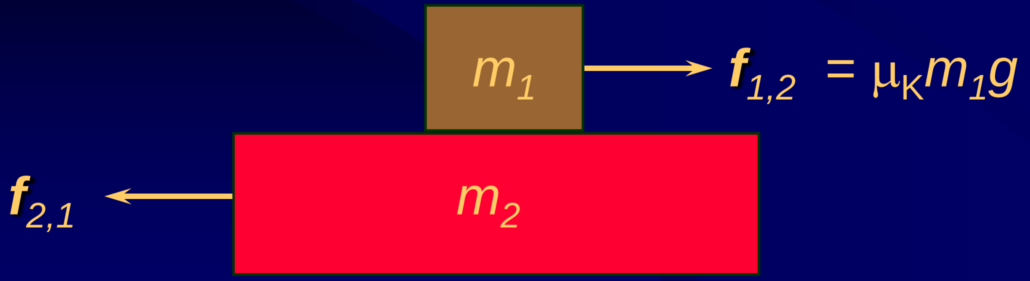


First draw FBD of the top box:

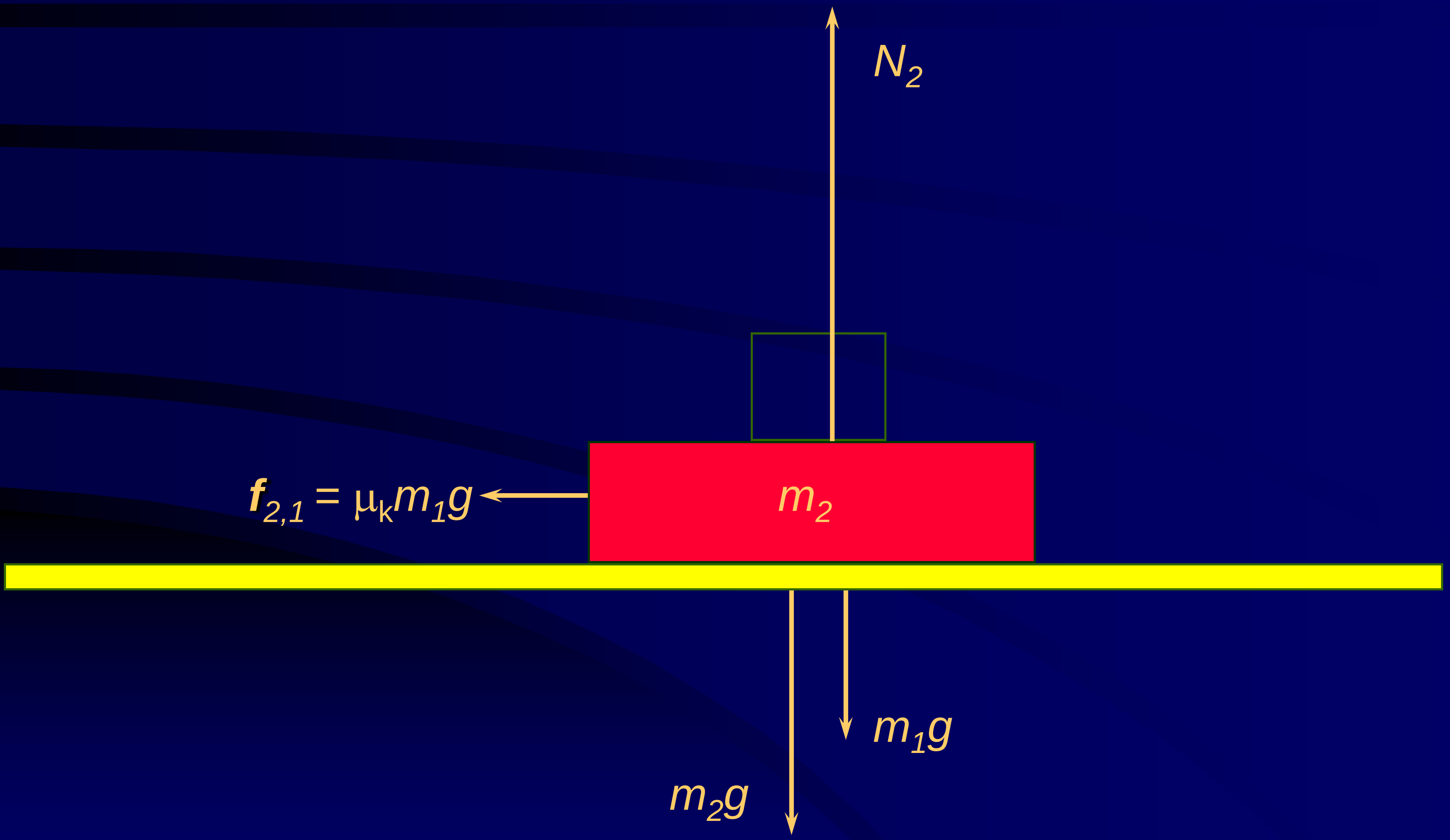


- Newtons 3rd law says the force *box 2 exerts on box 1* is <u>equal and opposite</u> to the force *box 1 exerts on box 2*.

As we just saw, this force is due to friction:



Now consider the FBD of box 2:



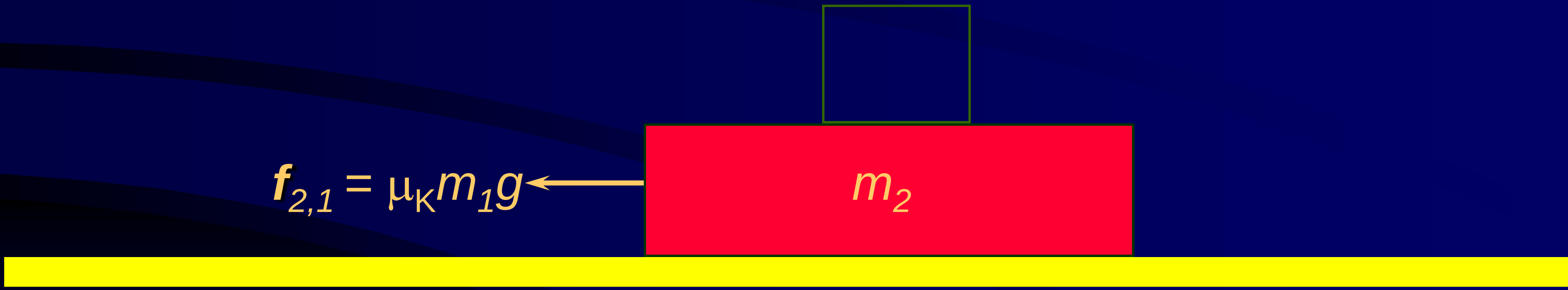
Finally, solve $F = ma$ in the horizontal direction:

$\Rightarrow \quad \mu_K m_1 g = m_2 a$

$\Rightarrow \quad a = \dfrac{m_1}{m_2}\mu_k g$

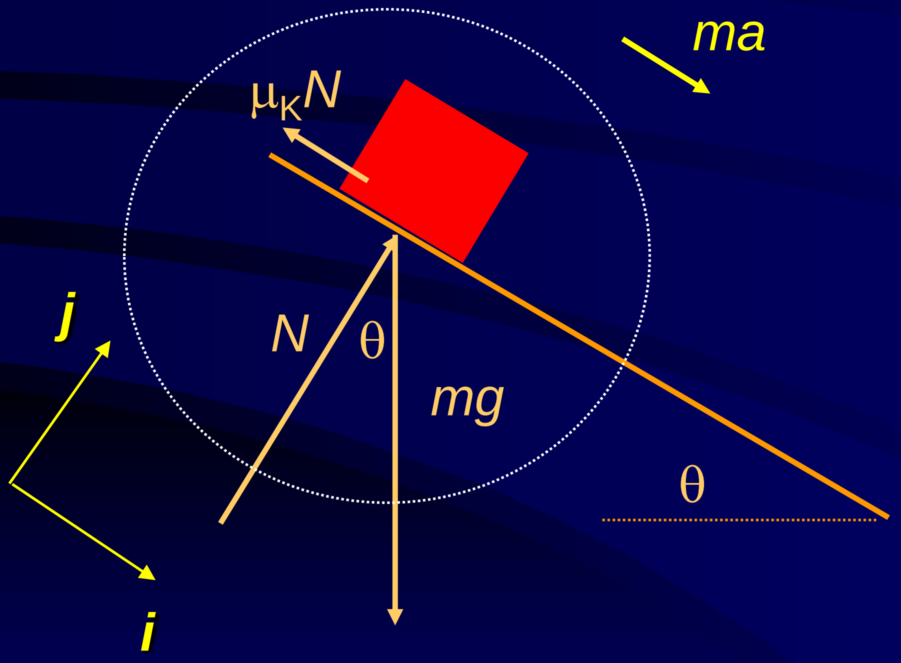
$$= \frac{1.5kg}{3kg} \times 0.51 \times 9.81 m/s^2$$

$\Rightarrow \quad a = 2.5\ m/s^2$



Inclined Plane with Friction:

What is a/g?



- Consider ***i*** and ***j*** components of $\boxed{F_{NET} = ma}$

$$i \Rightarrow mg \sin\theta - \mu_K N = ma$$

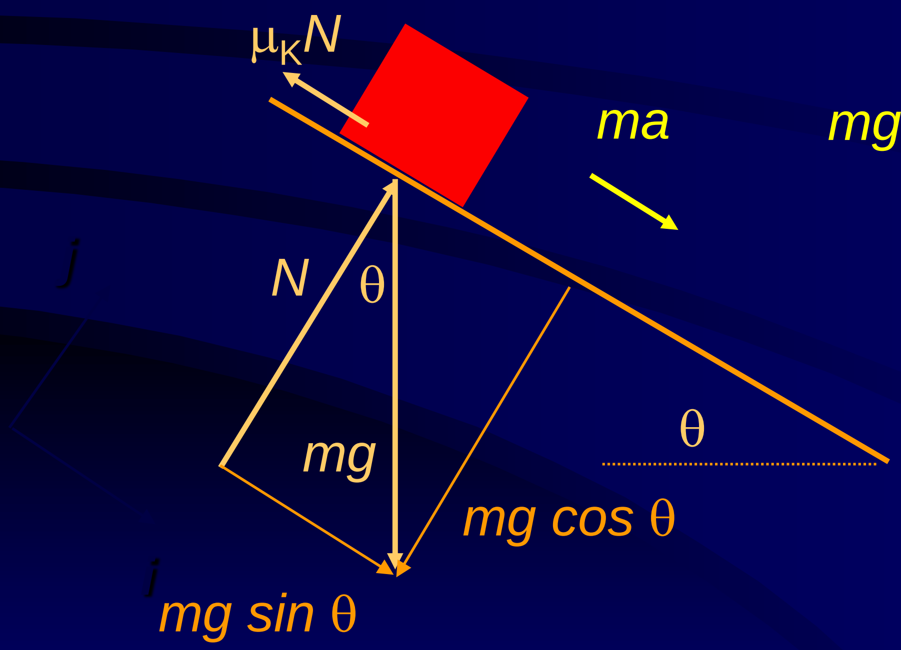
$$j \Rightarrow N = mg \cos\theta$$

$$\Downarrow$$

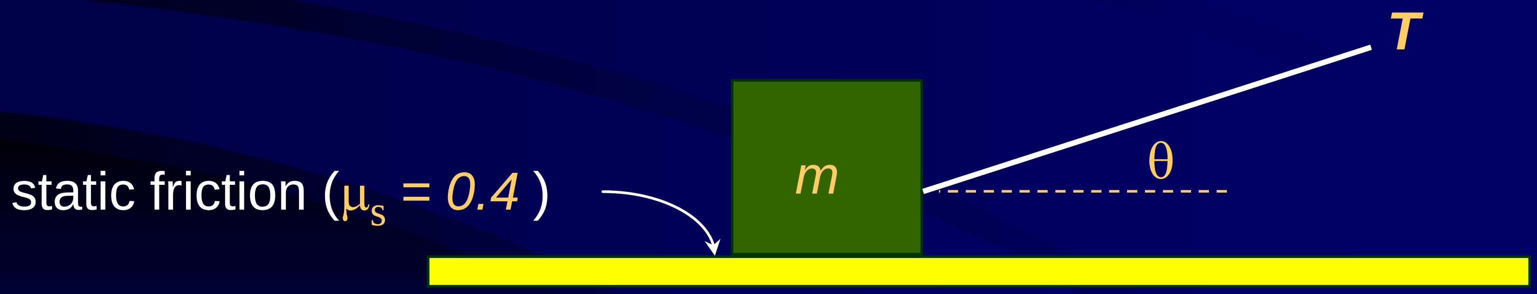
$$mg \sin\theta - \mu_K mg \cos\theta = ma$$

$$\Downarrow$$

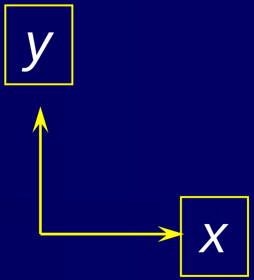
$$\boxed{a / g = \sin\theta - \mu_K \cos\theta}$$



- **A box of mass *m =10.21 kg* is at rest on a floor. The coefficient of static friction between the floor and the box is $\mu_s = 0.4$.**
- **A rope is attached to the box and pulled at an angle of $\theta = 30^o$ above horizontal with tension *T = 40 N*.**
  - **Does the box move?**



- Pick axes & draw FBD of box:

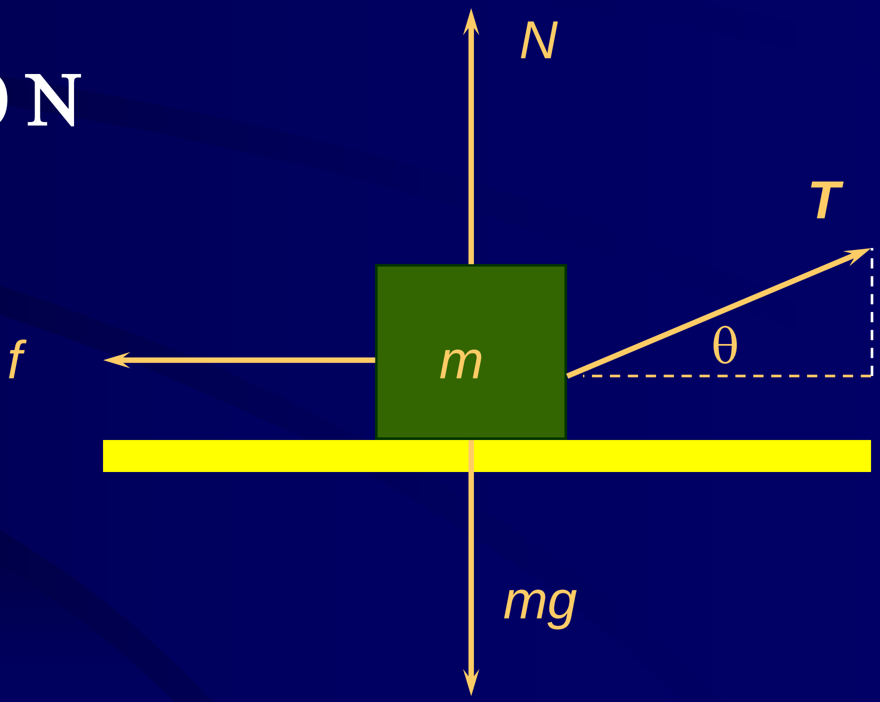


  - Apply $F_{NET} = ma$

$$N + T \sin\theta - mg = ma_Y = 0$$

$$N = mg - T \sin\theta = 80 \text{ N}$$

x: $T \cos\theta - f = ma_X$



The box will move if $T \cos\theta - f > 0$

$$T \cos\theta = 34.6\ N$$

$$f_{MAX} = \mu_s N = (0.4)(80N) = 32\ N$$

So $T \cos\theta > f_{MAX}$ and the box <u>does</u> move