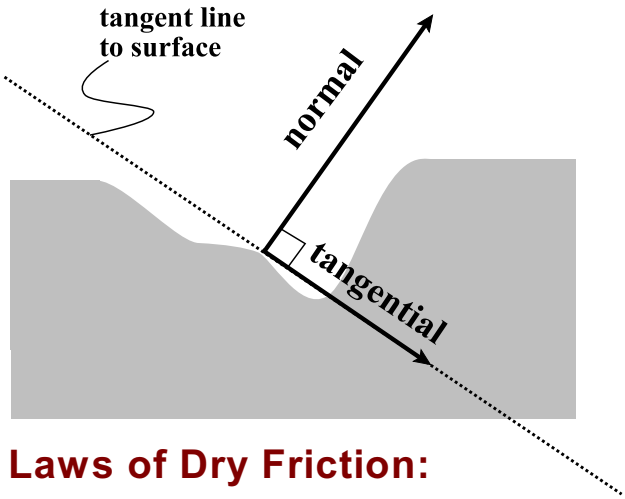
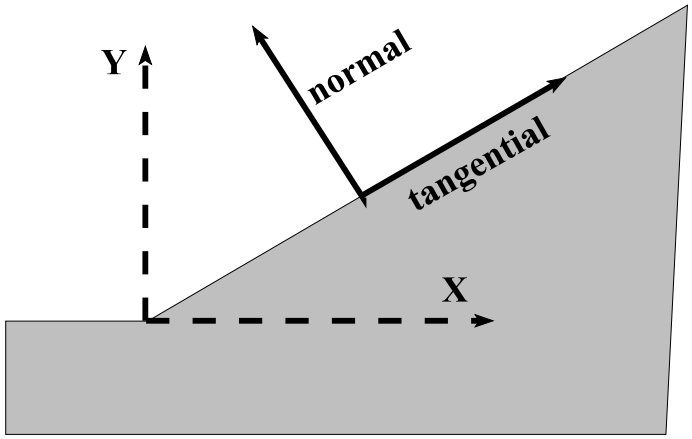
Friction

Normal and Tangential Axes:

- **normal axis** is perpendicular to surface
- **tangential axis** is parallel to surface





Laws of Dry Friction:

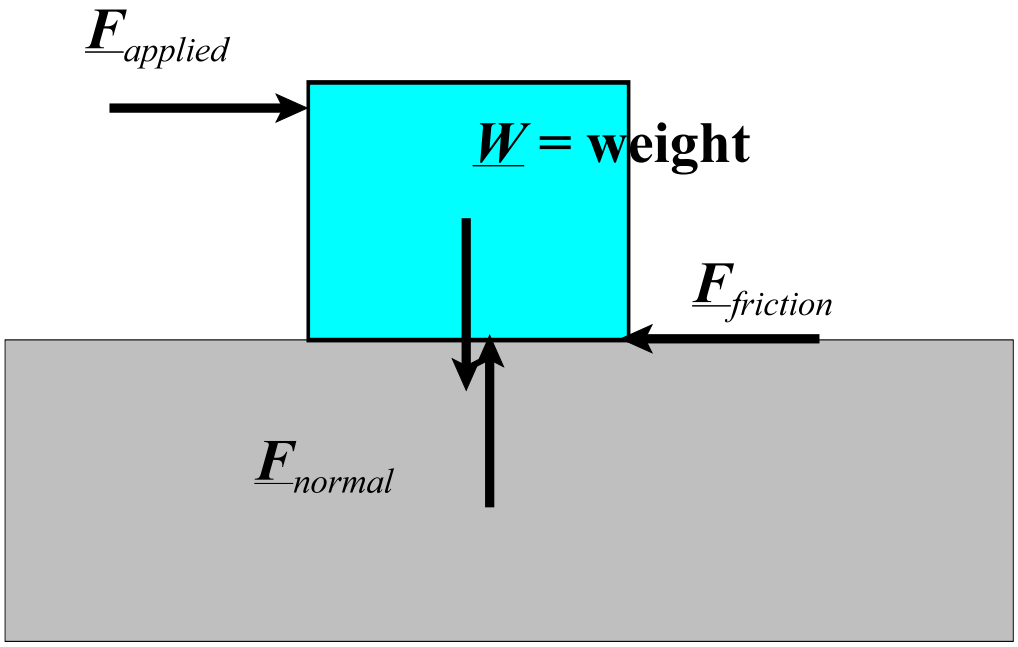
Static: maximum static friction $= F_{static} = {}_{static} F_{normal}$

Kinetic: maximum kinetic friction $= F_{kinetic} = {}_{kinetic} F_{normal}$

Coefficients of Static Dry Friction

Metal on metal	0.15 - 0.60
Metal on wood	0.20 - 0.60
Metal on stone	0.30 - 0.70
Wood on wood/leather	0.25 - 0.50
Stone on stone	0.40 - 0.70
Earth on earth	0.20 - 1.00
Rubber on concrete	0.60 - 0.90
Nylon on nylon	0.15 - 0.25
Bone on bone (cartilage)	0.10 - 0.20
Steel on Teflon	0.04 - 0.05
Metal of ice	0.02 - 0.05

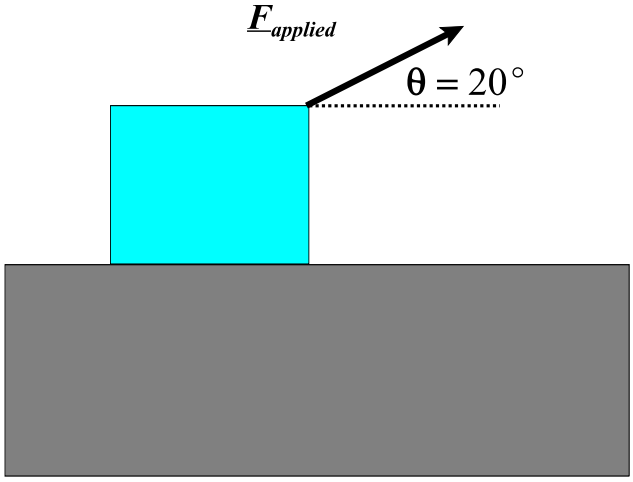
Forces of Friction:



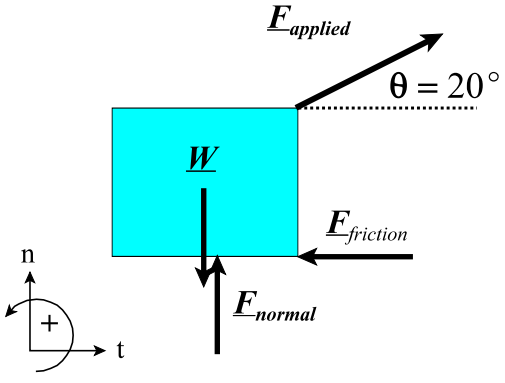
Example:

If $F_{applied}$ = 25.0 N, F_{static} = 100 N, W = 30.0 N, compute $F_{friction}$.

Space diagram



Free-body diagram



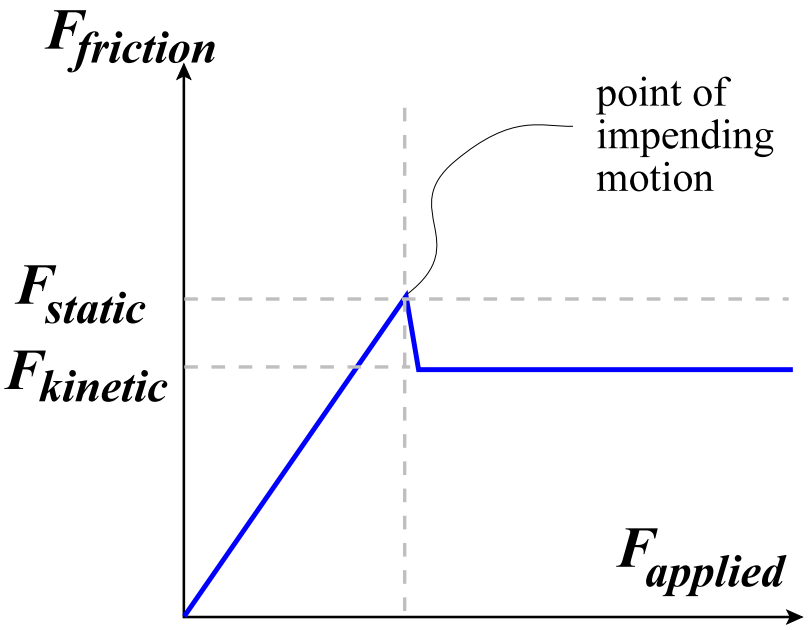
$F_t = 0$: $F_{friction} + F_{applied} \cos 20^\circ = 0$

therefore $F_{friction} = -25.0 \cos 20^\circ = -23.5$ N

(note answer must be > 100 newtons, i.e., max. static friction)

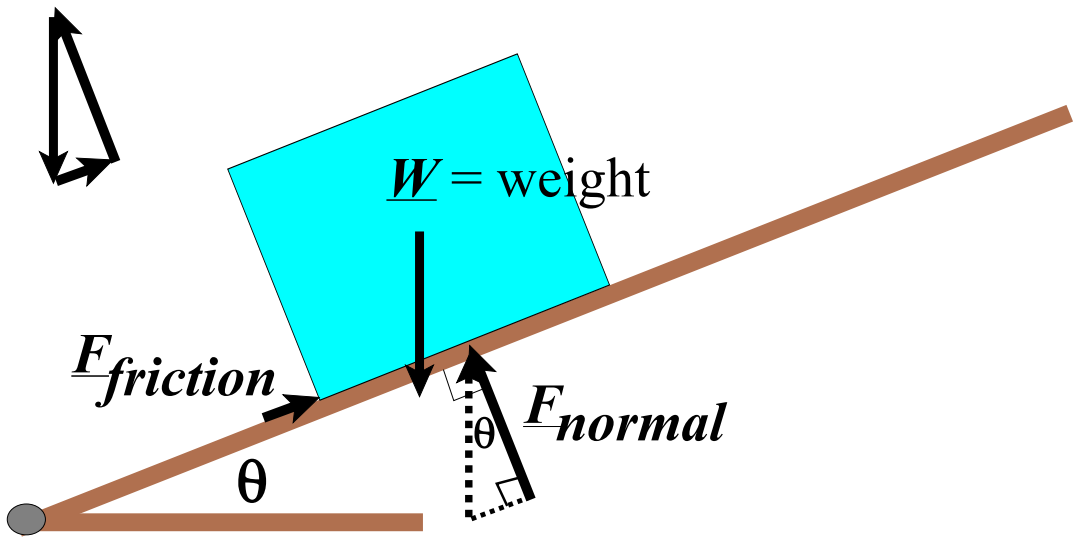
Relationship between Applied Force and Friction

- as applied force increases friction increases until a maximum is reached and slipping occurs
- maximum is called F_{static}
- after body starts to move frictional force drops to a new level called $F_{kinetic}$
- any further increase in the applied force is resisted by $F_{kinetic}$
- figure below is called the "standard model of friction"



Empirical Method for Calculating Coefficient of Static Friction

- cover a load and incline with two surfaces to be tested
- place load on an incline that can be raised at one end
- make sure incline and load are flat and clean
- increase incline until load just starts to slip
- measure angle of incline,
- repeat and obtain average angle
- coefficient of static friction = $_{static}$ = tan
- proof follows

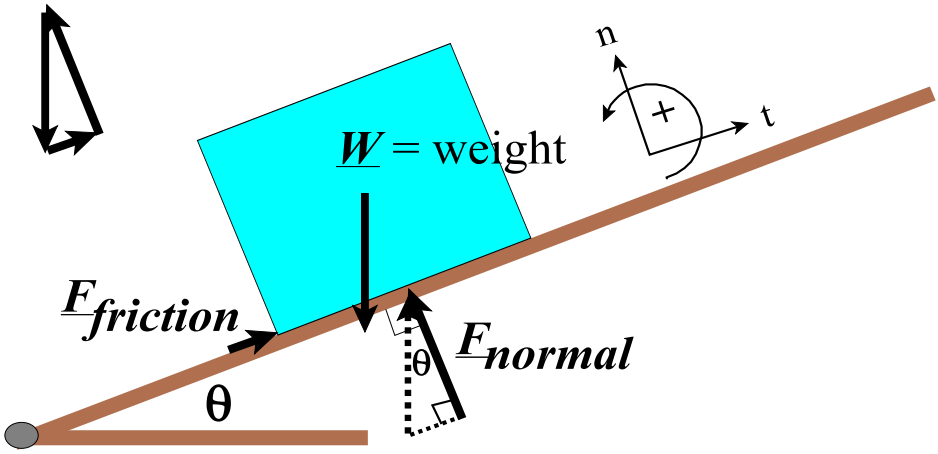


At instant of impending motion: $\mu_{static} = \tan\theta$

- coefficient of kinetic friction is more difficult to obtain
- tan of angle that keeps load moving at constant velocity

Angles of Friction

- angle of an incline at the point of **impending motion**
- tangent (tan) of this angle is the same as the coefficient of static friction



At instant of impending motion: $\mu_{static} = \tan\theta$

Proof:

$$\sum F_n = 0: \quad F_{normal} - W\cos\theta = 0$$

$$F_{normal} = W\cos\theta$$

$$\sum F_t = 0: \quad F_{static} - W\sin\theta = 0$$

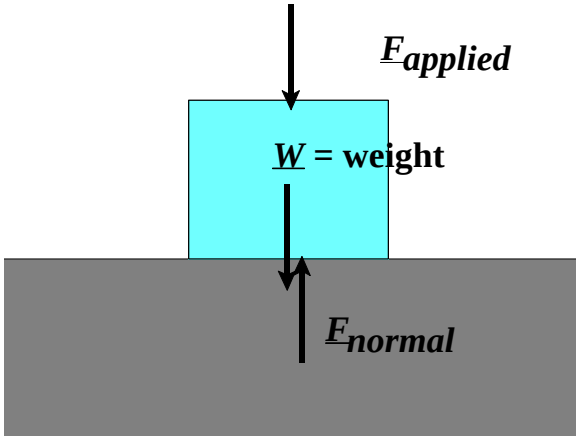
$$F_{static} = W\sin\theta$$

$$\mu_{static} = \frac{F_{static}}{F_{normal}} = \frac{W\sin\theta}{W\cos\theta} = \tan\theta$$

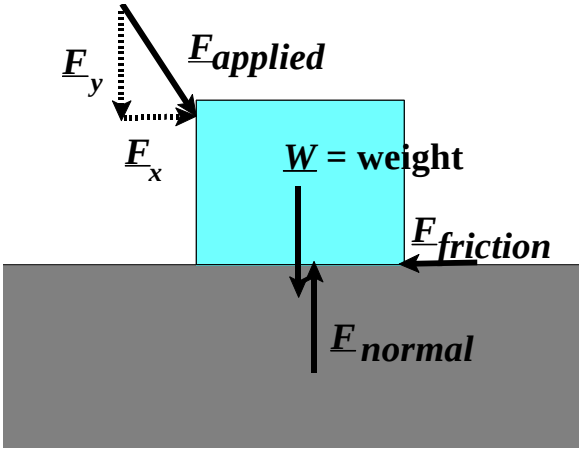
- To compute the **coefficient of kinetic friction**, lower the incline slowly until the mass just stops–this is the angle of kinetic friction.
- The tan of this angle is the coefficient of kinetic friction.

Frictional States

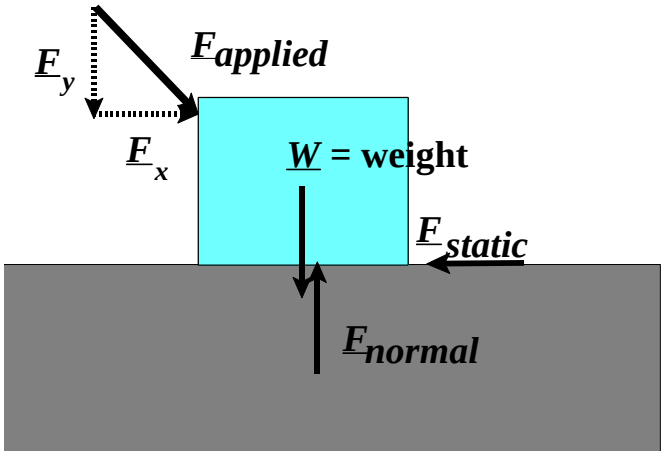
(a) no friction



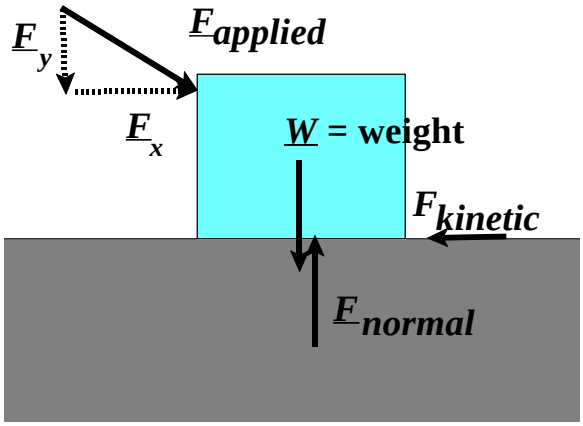
(b) no motion ($F_x < F_{static}$)



(c) motion impending ($F_x = F_{static}$)



(d) motion ($F_x > F_{static}$)



Measuring Friction using Force Platforms

- line load and force platform with surfaces to be tested
- pull load across clean level force platform
- record maximum horizontal force (F_x) at point load starts to move
- $_{static}$ = horizontal force / vertical force
- record horizontal force when load is moving
- $_{kinetic}$ = horizontal force / vertical force