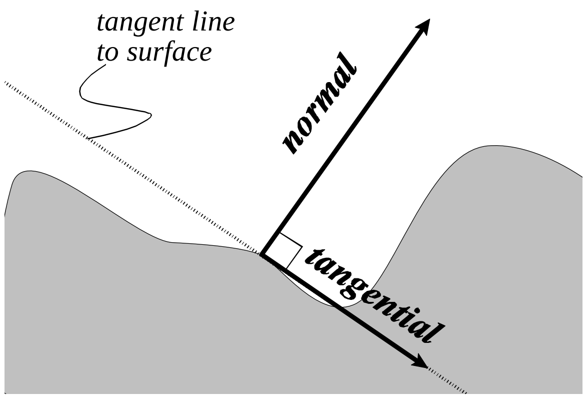
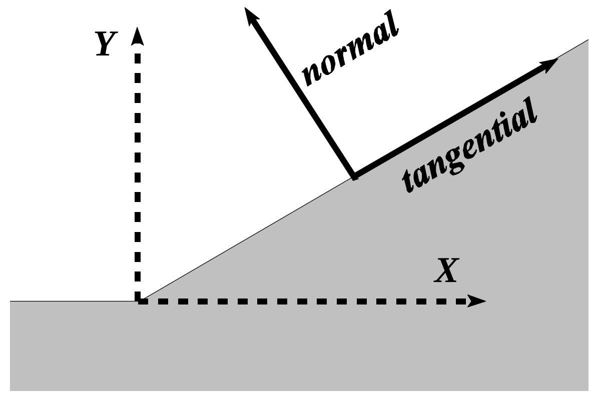
Friction

Normal and Tangential Axes

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





Laws of Dry Friction:

Static: F_{static} ' $\mu_{static} \, F_{normal}$

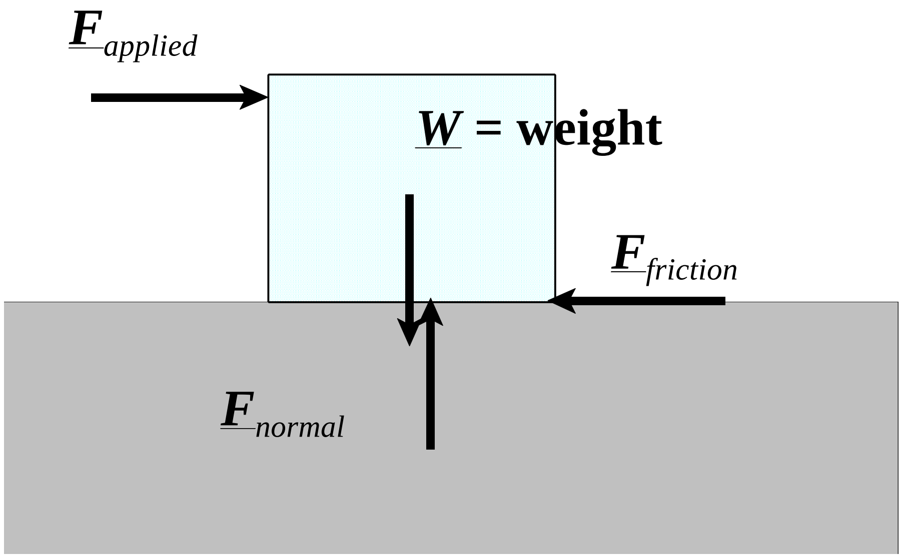
Kinetic $F_{kinetic}$ ' $\mu_{kinetic} \, F_{normal}$

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

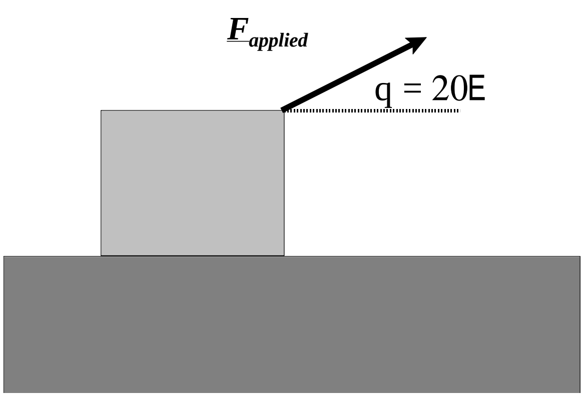
From: Robertson, Chapter 4

Forces of Friction:

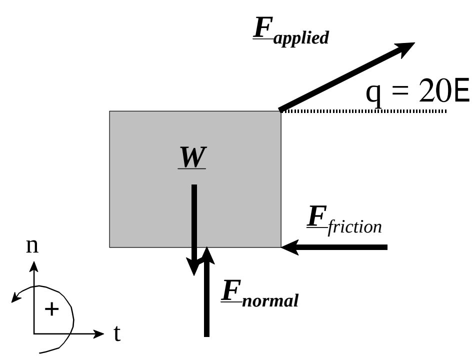


Example:

Space diagram



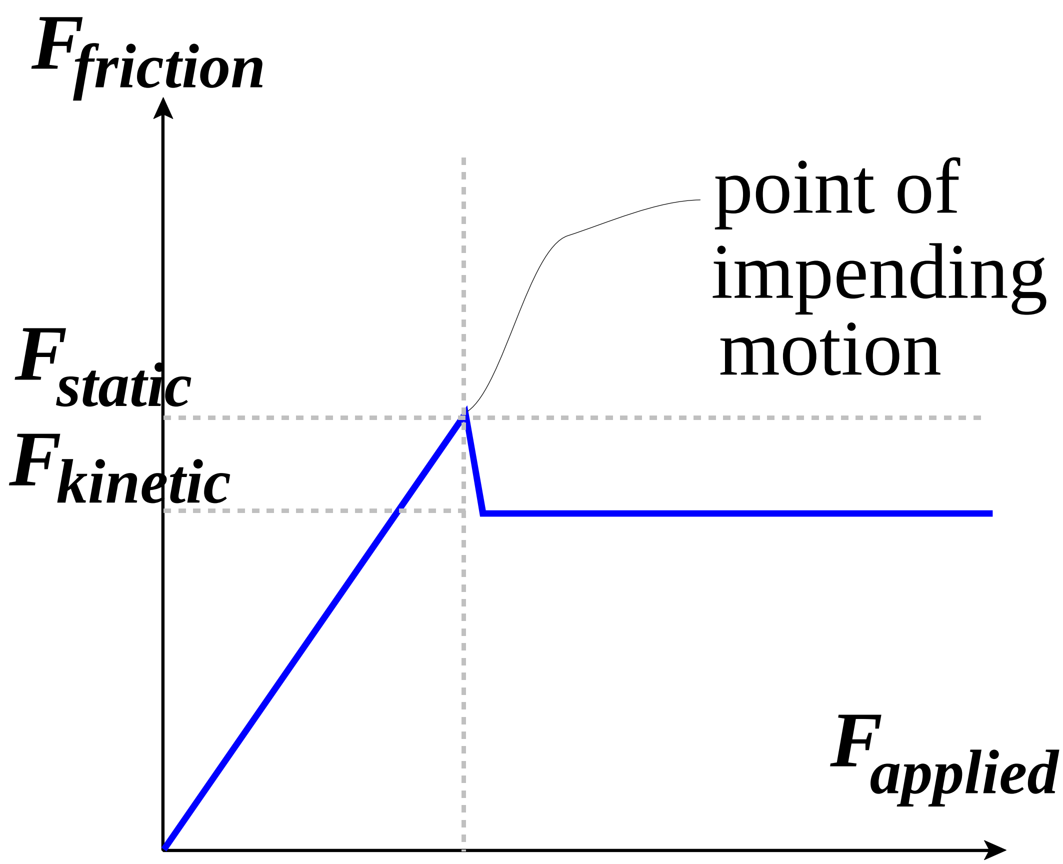
Free-body diagram



From: Robertson, Chapter 4

Relationship between Applied Force and Friction:

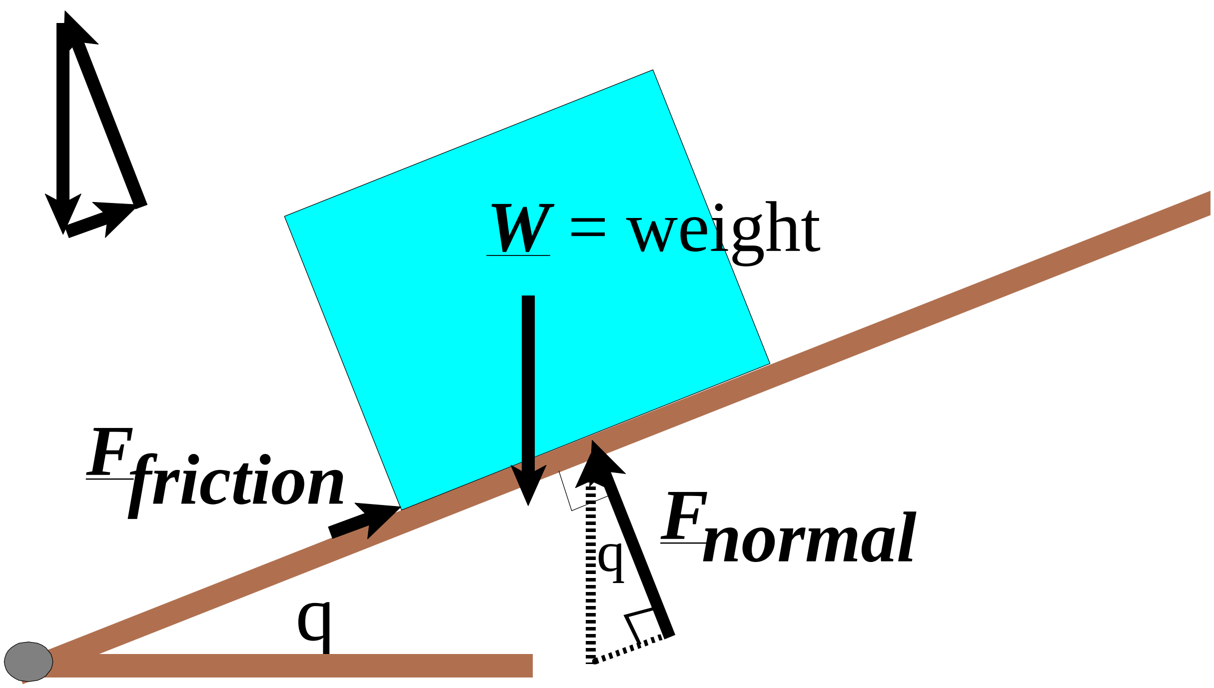
- as applied force increases friction increases until a maximum is reached and slipping occurs
- maximum is called F_{static}
- after body starts to move frictional force drops to a new level called $F_{kinetic}$
- any further increase in the applied force is resisted by $F_{kinetic}$



From: Robertson, Chapter 4

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, θ
- repeat and obtain average angle
- coefficient of static friction = μ_{static} = tan θ
- proof follows



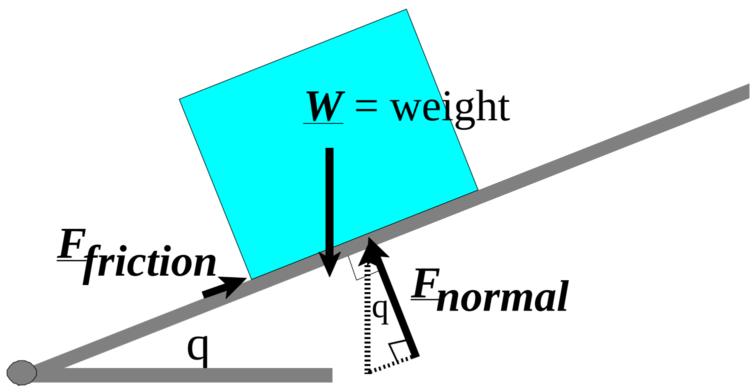
At instant of impending motion: $\mu_{static} = \tan\theta$

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

From: Robertson, Chapter 4

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: $\mu_s = \tan\theta$

Proof:

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

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

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

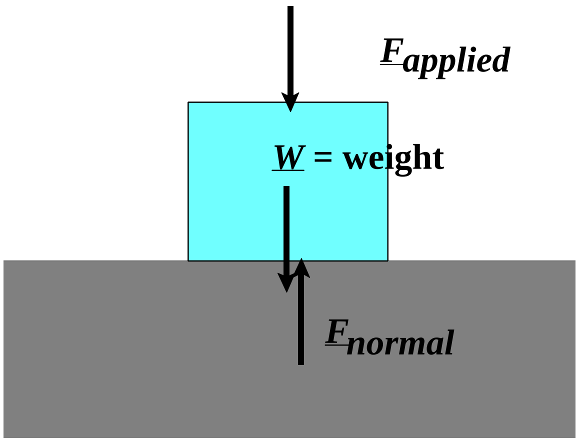
$$F_{static} = W\sin q$$

$$m_{static} = \frac{F_{static}}{F_{normal}} = \frac{W\sin q}{W\cos q} = \tan q$$

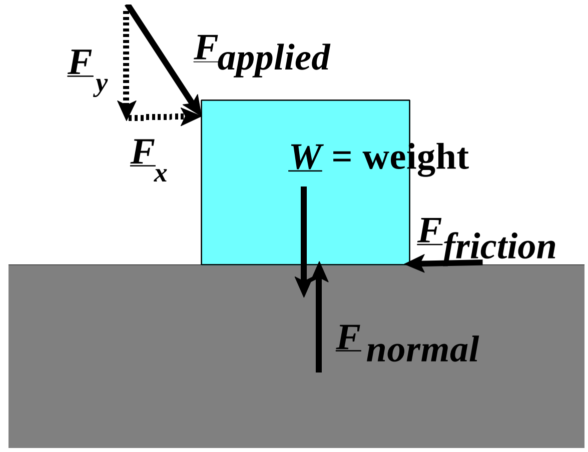
- to compute the **coefficient of kinetic friction**, lower the incline slowly until the mass just stops–this is the angle of kinetic friction
- as above the tan of this angle is the coefficient of kinetic friction

Frictional States

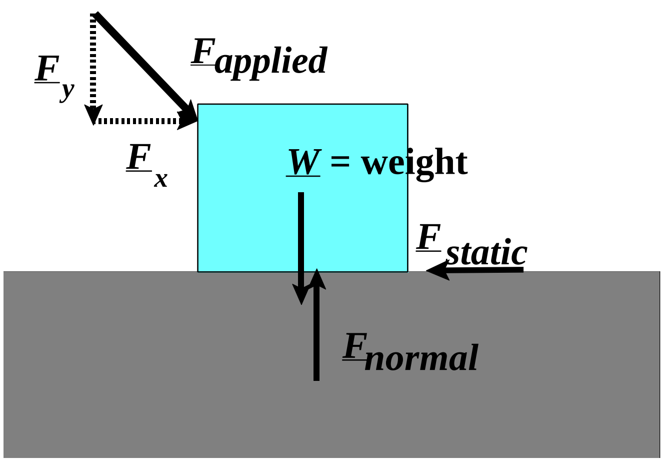
(a) no friction



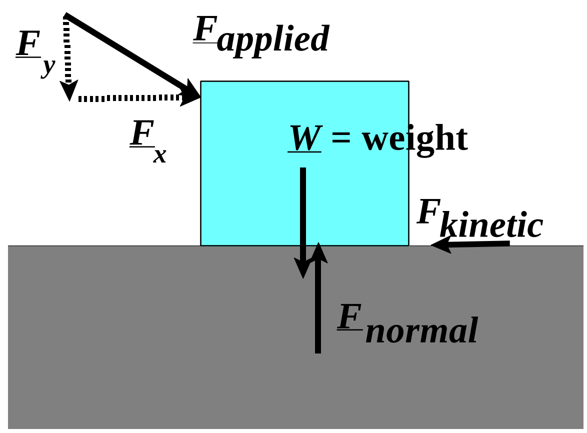
(b) no motion ($F_x < F_{static}$)



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



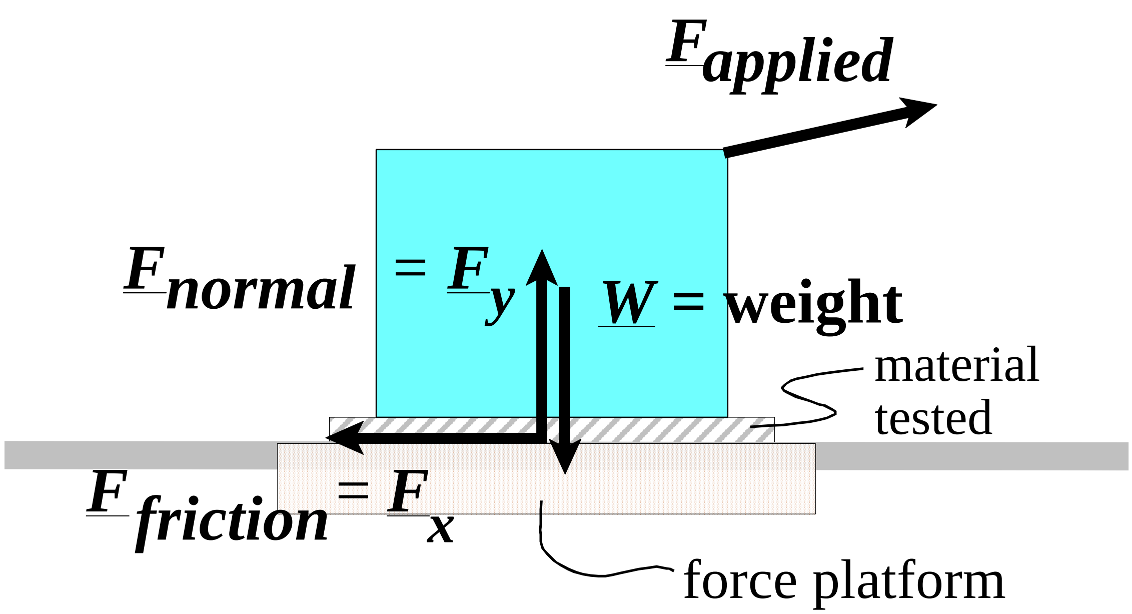
(d) motion ($F_x > F_{static}$)



From: Robertson, Chapter 4

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
- μ_{static} = horizontal force / vertical force
- record horizontal force when load is moving
- $\mu_{kinetic}$ = horizontal force / vertical force



From: Robertson, Chapter 4