DYNAMICS

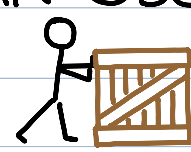
- DYNAMICS IS THE STUDY OF FORCES.

- A FORCE IS A PUSH OR PULL.
- FORCE IS A VECTOR.
- SI UNIT: NEWTON (N)

TYPES OF FORCES

- CONTACT FORCES: TOUCHING
  - APPLIED FORCE, F_A: A FORCE USED TO HELP MOVE AN OBJECT

    EXAMPLE

    PUSHING A BOX 

  - FORCE OF FRICTION, F_f: A FORCE THAT OPPOSES SLIDING MOTION BETWEEN SURFACES
  - NORMAL FORCE, F_N: THE FORCE A SURFACE EXERTS ON AN OBJECT TO SUPPORT IT. THE NORMAL FORCE ALWAYS ACTS PERPENDICULAR TO THE SURFACE.

- TENSION, F_T : THE PULL EXERTED BY A STRING, ROPE OR CABLE
- SPRING FORCE, F_s : THE FORCE A SPRING EXERTS TO RESTORE IT TO ITS NORMAL SHAPE

- AT-A-DISTANCE FORCES: NOT TOUCHING
  - GRAVITATIONAL FORCE (AKA WEIGHT), F_g : THE ATTRACTION BETWEEN TWO OBJECTS, GENERALLY EARTH AND AN OBJECT

$$\boxed{F_g = mg}$$

F_g : GRAVITATIONAL FORCE (N)
m : MASS (kg)
g : GRAVITATIONAL FIELD STRENGTH ($9.8 \frac{N}{kg}$)

  - ELECTROSTATIC FORCE
  - MAGNETIC FORCE

FREE-BODY DIAGRAMS

- A FREE-BODY DIAGRAM IS USED TO SHOW THE MAGNITUDE AND DIRECTION OF ALL THE FORCES ACTING ON AN OBJECT.
- USE A DOT OR BOX TO REPRESENT THE OBJECT.
- USE ARROWS TO REPRESENT THE FORCES.
  - ARROWS POINT OUTWARDS FROM THE OBJECT.
  - THE LENGTH OF AN ARROW SHOWS THE SIZE OF THE FORCE.
  - FORCES MUST BE LABELLED.

  IF YOU ARE UNSURE OF WHAT FORCES ARE ACTING ON AN OBJECT, A ROUGH RULE IS EVERYTHING TOUCHING THE OBJECT, PLUS GRAVITY.

EXAMPLE

DRAW A FREE-BODY DIAGRAM FOR THE FOLLOWING SITUATIONS:

a) A BOOK AT REST ON A TABLE

b) A MAN PUSHING A BOX

c) A BASEBALL PLAYER SLIDING TO SECOND BASE

NET FORCE

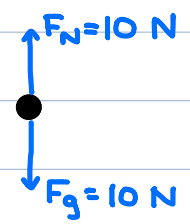
- THE NET FORCE (F_{NET}) (SUM/TOTAL) IS THE SUM OF ALL THE FORCES.
- THE NET FORCE IS NOT A REAL FORCE (IT IS NOT SHOWN ON A FREE-BODY DIAGRAM).

REMEMBER: FORCES HAVE DIRECTION. THIS MEANS THAT YOU ADD FORCES IN THE SAME DIRECTION AND SUBTRACT FORCES IN THE OPPOSITE DIRECTION.

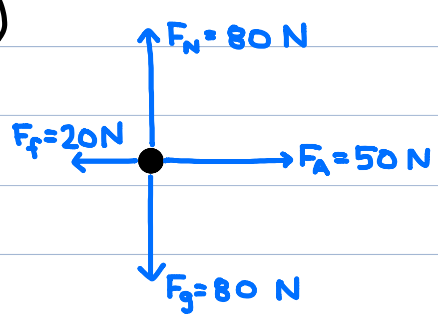
EXAMPLE

WHAT IS THE NET FORCE?

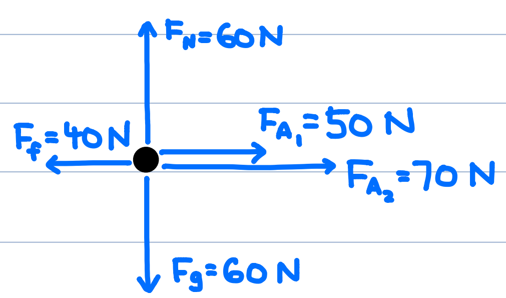
a)



b)



c)



NEWTON'S LAWS

- FIRST LAW: LAW OF INERTIA
  - IF ALL THE FORCES ACTING ON A BODY ARE BALANCED, THEN THE OBJECT WILL NOT CHANGE SPEED OR DIRECTION.

CONSTANT VELOCITY
$a = 0$

AN OBJECT AT REST HAS A TENDENCY TO REMAIN AT REST. AN OBJECT IN MOTION HAS A TENDENCY TO REMAIN IN MOTION.

- SECOND LAW: $F_{NET} = ma$
  - IF THERE IS AN UNBALANCED FORCE ACTING ON AN OBJECT, IT WILL ACCELERATE IN THE DIRECTION OF THE NET FORCE IN INVERSE PROPORTION TO ITS MASS.

MASS RESISTS ACCELERATION
MORE MASS = MORE INERTIA

- THIRD LAW: ACTION-REACTION
  - IF OBJECT A EXERTS A FORCE ON OBJECT B, THEN B EXERTS AN EQUAL FORCE BACK UPON A IN THE OPPOSITE DIRECTION.

FORCES ALWAYS OCCUR IN PAIRS. THE ACTION-REACTION FORCES ARE NEVER ON THE SAME OBJECT.

- TWO POSSIBILITIES:
  - $F_{NET} = 0$
    - BALANCED FORCES
    - NEWTON'S FIRST LAW APPLIES.
      - NO ACCELERATION
  - $F_{NET} \neq 0$
    - UNBALANCED FORCES
    - NEWTON'S SECOND LAW APPLIES.
      - THE OBJECT ACCELERATES.

$$\vec{F}_{NET} = m\vec{a}$$

$\vec{F}_{NET}$: NET FORCE (N)
m : MASS (kg)
$\vec{a}$: ACCELERATION ($\frac{m}{s^2}$)

EXAMPLE

A 2500 kg ROCKET-PROPELLED PROJECTILE IS AIMED UPWARDS AND HAS A THRUST OF 35 000 N FROM ITS ENGINES. ASSUMING NO AIR RESISTANCE, AT WHAT RATE DOES IT ACCELERATE?

1. DRAW A FREE-BODY DIAGRAM.
2. WRITE DOWN NEWTON'S SECOND LAW ($F_{NET} = ma$).
3. REPLACE F_{NET} WITH THE SUM OF ALL FORCES PARALLEL TO MOTION.
4. ALGEBRAICALLY SOLVE FOR THE UNKNOWN.
5. PLUG IN VALUES.

- YOU MAY SOMETIMES NEED TO USE KINEMATICS TO SOLVE DYNAMICS PROBLEMS.
- THE LINK BETWEEN NEWTON'S SECOND LAW AND THE KINEMATICS EQUATIONS IS ACCELERATION.

EXAMPLE

A 2200 kg CAR IS TRAVELLING AT 12 $\frac{m}{s}$. THE CAR BRAKES AND COMES TO REST OVER A DISTANCE OF 8.0 m. WHAT IS THE FORCE OF FRICTION AS THE CAR BRAKES?

FRICTION

$$F_f = \mu F_N$$

GREEK LETTER "MU" PRONOUNCED *MEW*

F_f : FORCE OF FRICTION (N)

μ : COEFFICIENT OF FRICTION

F_N : NORMAL FORCE (N)

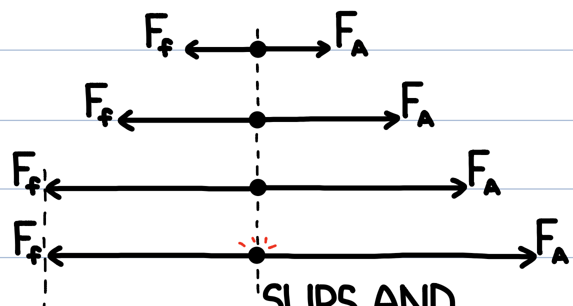
- FRICTION ALWAYS ACTS AGAINST MOTION/INTENDED MOTION.

- TO DETERMINE F_N, LOOK AT THE FORCES PERPENDICULAR TO THE SURFACE; THESE FORCES ARE BALANCED (I.E. $\Sigma F_{\perp} = 0$).

SIGMA MEANING SUM OF

F_N WILL OFTEN EQUAL mg BUT NOT ALWAYS

- STATIC FRICTION IS USED WHEN AN OBJECT IS NOT MOVING
- AT REST, F_f WILL ALWAYS GROW TO MATCH ANY PULL UNTIL A MAXIMUM IS REACHED.

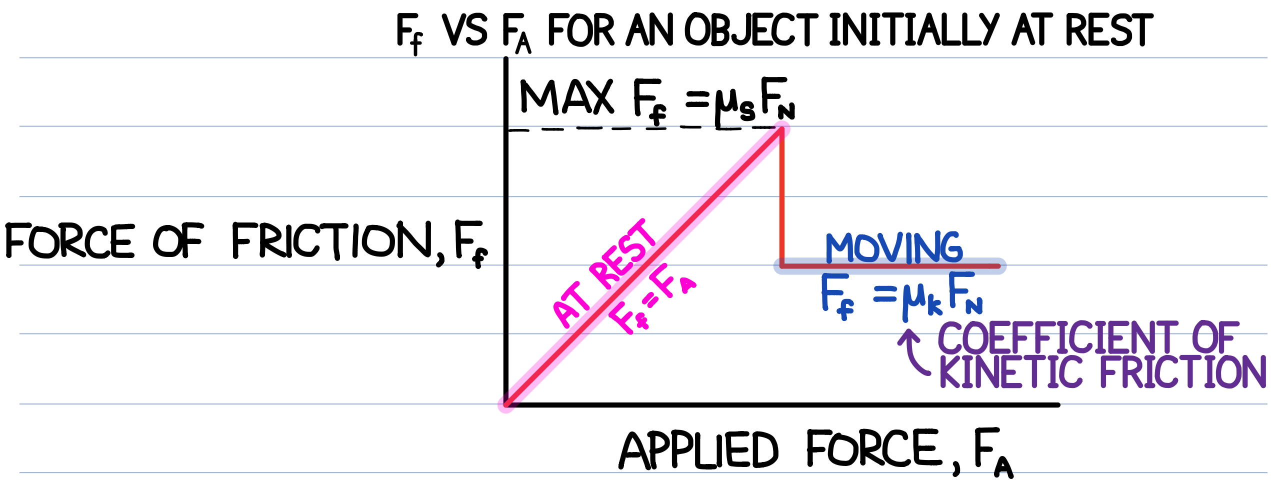


MAX $F_f = \mu_s F_N$

COEFFICIENT OF STATIC FRICTION

IF YOU WANT TO FIND THE MINIMUM FORCE REQUIRED TO MOVE AN OBJECT FROM REST, USE THE COEFFICIENT OF STATIC FRICTION, μ_s, AND AN ACCELERATION OF ZERO.

· KINETIC FRICTION IS USED WHEN AN OBJECT IS SLIDING OVER A SURFACE.



EXAMPLE

STUDENTS PLAN TO PUSH THE PRINCIPAL'S CAR (2500 kg) FROM ITS PARKING SPOT.

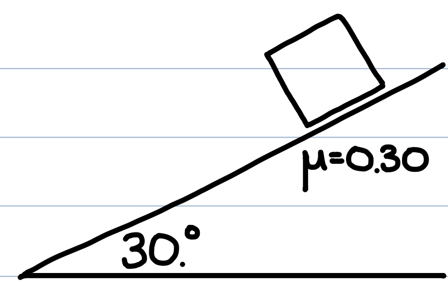
a) IF μ_s FOR ASPHALT AND RUBBER IS 0.65, HOW MUCH FORCE WILL THIS REQUIRE?

BEFORE $F_{NET} = ma$, SOLVE FOR F_N BY BALANCING FORCES PERPENDICULAR TO MOTION.

b) AFTER THE CAR STARTS MOVING, THE STUDENTS CONTINUE TO PUSH THE CAR WITH THE SAME FORCE. IF THE CAR ACCELERATES AT 0.50 $\frac{m}{s^2}$, WHAT IS THE COEFFICIENT OF KINETIC FRICTION, μ_k?

EXAMPLE

A BOX IS ON A RAMP. IF THE COEFFICIENT OF FRICTION BETWEEN THE BOX AND THE RAMP IS 0.30, AT WHAT RATE DOES THE BOX ACCELERATE?



1. DRAW A FREE-BODY DIAGRAM.

2. RESOLVE ALL FORCES INTO PARALLEL AND PERPENDICULAR COMPONENTS.

3. SOLVE FOR F_N BY BALANCING FORCES PERPENDICULAR TO MOTION.

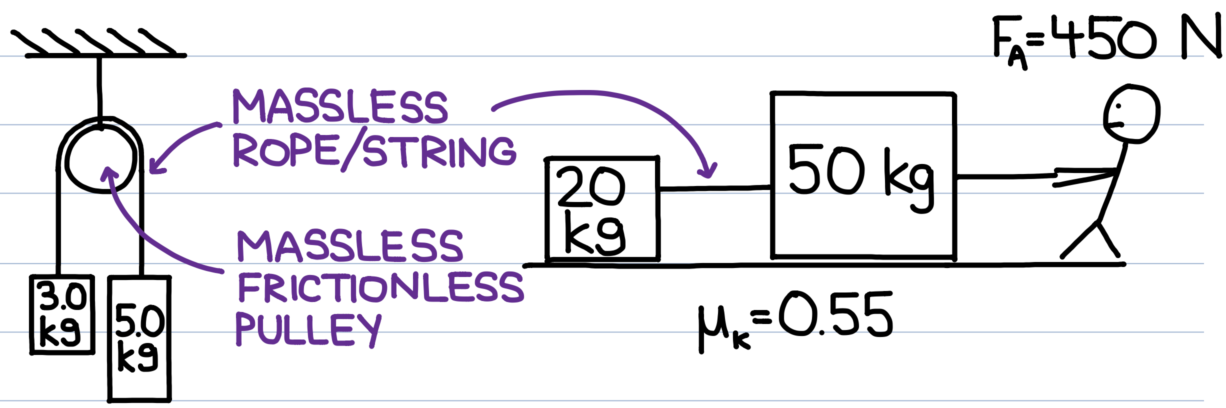
4. WRITE DOWN NEWTON'S SECOND LAW ($F_{NET} = ma$).

⑤ REPLACE F_{NET} WITH THE SUM OF ALL FORCES PARALLEL TO MOTION.

⑥ ALGEBRAICALLY SOLVE FOR THE UNKNOWN.

⑦ PLUG IN VALUES.

MULTI-BODY SYSTEMS

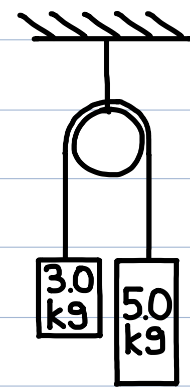


- KEY IDEAS:
  - BOTH MASSES WILL HAVE THE SAME MAGNITUDE OF ACCELERATION.
  - ONE ROPE/STRING CAN ONLY HAVE ONE TENSION.
  - TENSION CAN ONLY PULL (NOT PUSH).

- TO SOLVE FOR ACCELERATION, ANALYZE THE SYSTEM AS A WHOLE.
- TO SOLVE FOR TENSION, ISOLATE THE MASSES.

EXAMPLE

DETERMINE THE ACCELERATION OF THE SYSTEM AND THE TENSION OF THE ROPE.



① DRAW THE LINE OF MOTION AND LABEL THE POSITIVE DIRECTION.

② DRAW AND LABEL THE FORCES ON BOTH MASSES.

③ WRITE DOWN NEWTON'S SECOND LAW ($F_{NET} = Ma$).

MASS OF SYSTEM ($m_1 + m_2$)

④ REPLACE F_{NET} WITH THE SUM OF ALL FORCES PARALLEL TO MOTION (USE THE ARROW FROM ①).

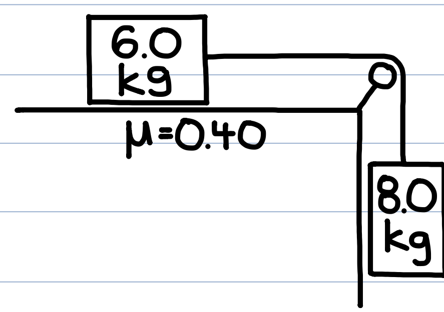
⑤ CONTINUE AS ANY DYNAMICS QUESTION.

① DRAW A FREE-BODY DIAGRAM FOR ONE OF THE MASSES.

② CONTINUE AS ANY DYNAMICS QUESTION.

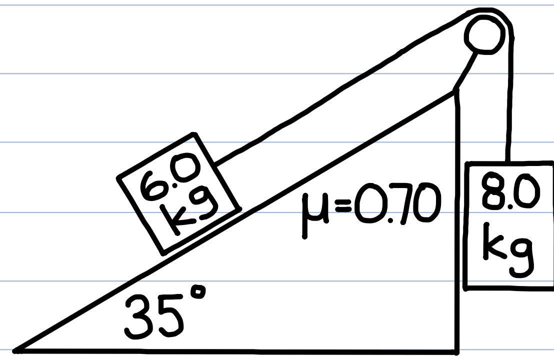
EXAMPLE

DETERMINE THE ACCELERATION OF THE SYSTEM AND THE TENSION OF THE ROPE.



EXAMPLE

DETERMINE THE ACCELERATION OF THE SYSTEM AND THE TENSION OF THE ROPE.



① DRAW THE LINE OF MOTION AND LABEL THE POSITIVE DIRECTION.

② DRAW AND LABEL THE FORCES ON BOTH MASSES.

③ RESOLVE ALL FORCES INTO PARALLEL AND PERPENDICULAR COMPONENTS.

④ SOLVE FOR F_N BY BALANCING FORCES PERPENDICULAR TO MOTION.

⑤ WRITE DOWN NEWTON'S SECOND LAW ($F_{NET} = Ma$).

MASS OF SYSTEM ($m_1 + m_2$)

⑥ REPLACE F_{NET} WITH THE SUM OF ALL FORCES PARALLEL TO MOTION (USE THE ARROW FROM ①).

⑦ CONTINUE AS ANY DYNAMICS QUESTION.

① DRAW A FREE-BODY DIAGRAM FOR ONE OF THE MASSES.

② CONTINUE AS ANY DYNAMICS QUESTION.

SPRINGS AND HOOKE'S LAW

- EACH SPRING HAS AN EQUILIBRIUM POSITION.
- HOOKE'S LAW: THE RESTORING OF FORCE A SPRING IS PROPORTIONAL TO HOW MUCH THE SPRING IS STRETCHED OR COMPRESSED.

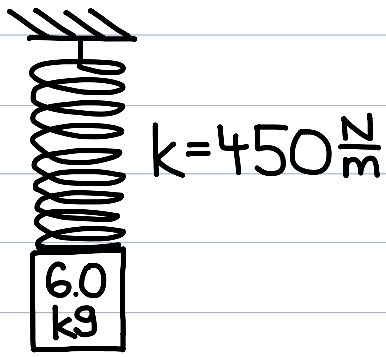
$$F_s = k\Delta x = k(x - x_0)$$

F_s : SPRING FORCE (N)
k : SPRING CONSTANT ($\frac{N}{m}$)
Δx : DISPLACEMENT FROM EQUILIBRIUM POSITION (m) ← HOW MUCH THE SPRING HAS BEEN STRETCHED OR COMPRESSED
x : STRETCHED/COMPRESSED LENGTH (m)
x_0 : EQUILIBRIUM LENGTH (m)

- THE SPRING CONSTANT, k, IS DEPENDENT ON THE SPRING.
  - GREATER VALUE MEANS STIFFER SPRING

EXAMPLE

DETERMINE HOW FAR THE SPRING IS STRETCHED FROM ITS EQUILIBRIUM POSITION.



UNIVERSAL GRAVITATION

- THERE IS A GRAVITATIONAL FORCE BETWEEN ANY TWO MASSES.

$$F_g = G\frac{m_1 m_2}{r^2}$$

OFTEN WRITTEN AS $F_g = G\frac{Mm}{r^2}$

F_g : GRAVITATIONAL FORCE (N)

G : GRAVITATIONAL CONSTANT ($6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$)

m_1, m_2 : MASSES (kg)

r : DISTANCE BETWEEN THE CENTRES OF MASS (m)

EQUIVALENT TO ACCELERATION DUE TO GRAVITY

- THE GRAVITATIONAL FIELD STRENGTH IS THE GRAVITATIONAL FORCE ACTING ON EACH KILOGRAM OF MASS.

$$g = \frac{F_g}{m} = G\frac{M}{r^2}$$

EQUIVALENT TO $\frac{m}{s^2}$

g : GRAVITATIONAL FIELD STRENGTH ($\frac{N}{kg}$)

F_g : GRAVITATIONAL FORCE (N)

m : MASS IN FIELD (kg)

G : GRAVITATIONAL CONSTANT ($6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$)

M : MASS GENERATING THE FIELD (kg) — TYPICALLY A LARGE BODY (E.G. PLANET)

r : DISTANCE FROM THE CENTRE OF MASS (m)

EXAMPLE

WHAT IS THE FORCE OF GRAVITY ON A 75 kg ASTRONAUT 1000 km ABOVE THE EARTH? HOW DOES THIS COMPARE WITH THE FORCE OF GRAVITY ON THE SURFACE OF EARTH?

RADIUS OF EARTH = 6380 km

MASS OF EARTH = 5.98×10^{24} kg

EXAMPLE

WHAT IS THE FORCE OF GRAVITY BETWEEN YOU AND THE PERSON BESIDE YOU?

EXAMPLE

SHOW THAT THE ACCELERATION DUE TO GRAVITY IS $9.8\,\frac{m}{s^2}$ ON THE SURFACE OF EARTH.