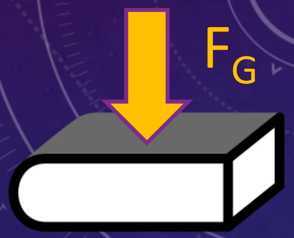
APPLYING NEWTON’S LAWS

PES 1000 – PHYSICS IN EVERYDAY LIFE

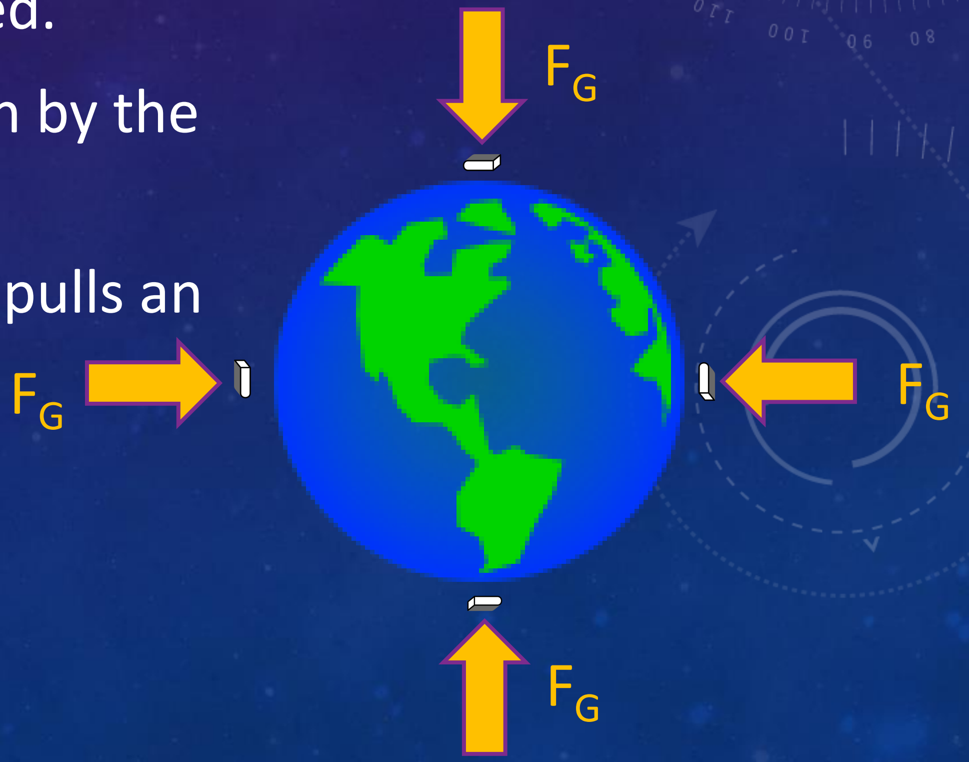
FORCE MODELS

- Newton's Second Law of Motion: $\vec{F}_{net} = m\vec{a}$ or $\sum \vec{F} = m\vec{a}$
- Net force is the sum of all of the forces, taking into account both their size and direction.
- We need a mathematical model for each force.
- I'll use the notation of a capital F for force, with a subscript indicating the source of that force
  - e.g. F_G for gravity, F_D for drag force, F_f for frictional force, etc.
- We don't include inertial resistance to acceleration in the list of forces; it is what opposes those forces (Newton's third law).
- $\vec{F}_G + \vec{F}_D + \vec{F}_f \ldots = m\vec{a}$

GRAVITATIONAL FORCE (NEAR THE SURFACE OF EARTH)

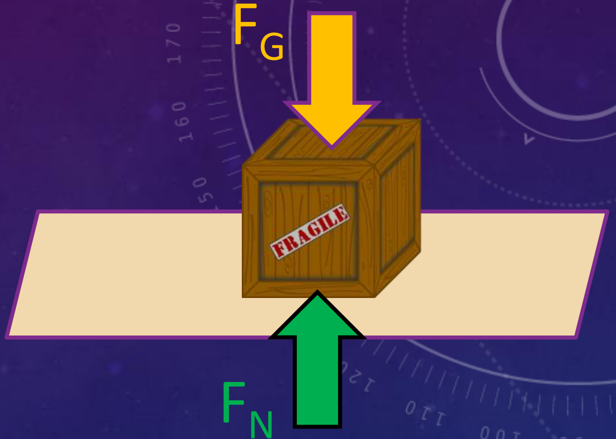


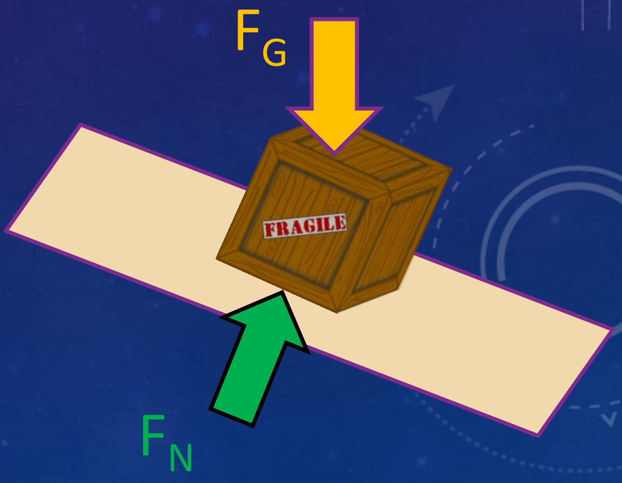
- We have seen the model for gravitational force: $F_G = m * g$, where g=gravitational acceleration (9.81 m/s^2)
- Gravitational force varies slightly with altitude above sea level, but this difference is very small, and is usually ignored.
- Gravitational force is a vector; the magnitude is given by the above formula, and the direction is 'down'.
  - In fact, 'down' is defined by the direction gravity pulls an object.



CONTACT FORCES

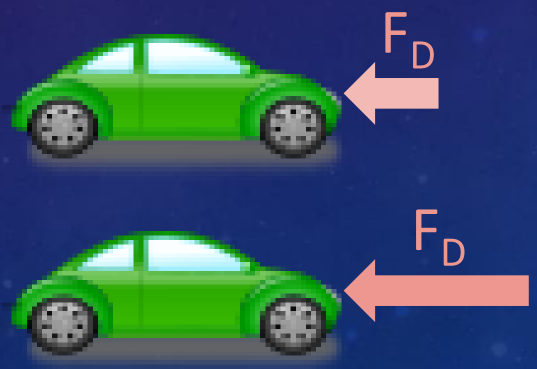
- Due to electric repulsion forces between molecules on the surfaces of two solid objects, the surfaces of the objects can't pass through each other.
  - This generates a force between them, called the 'normal force', F_N.
  - The force is perpendicular (normal) to the plane of the surfaces where they contact.
  - The force is present only while the surfaces are in contact.
- We use Newton's third law to find this force.
  - Its size is the sum of all the forces pressing the surfaces together.
  - Its direction depends on which object we are talking about.
    - In the top diagram, if it is the box we are interested in, the floor pushes up on the block.





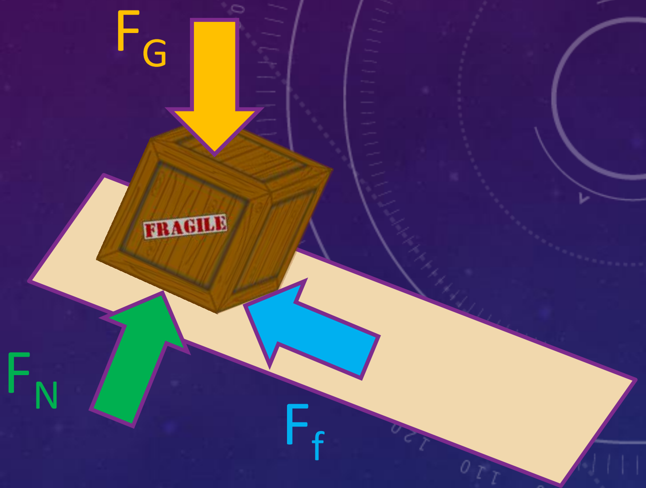
FLUID DRAG FORCE

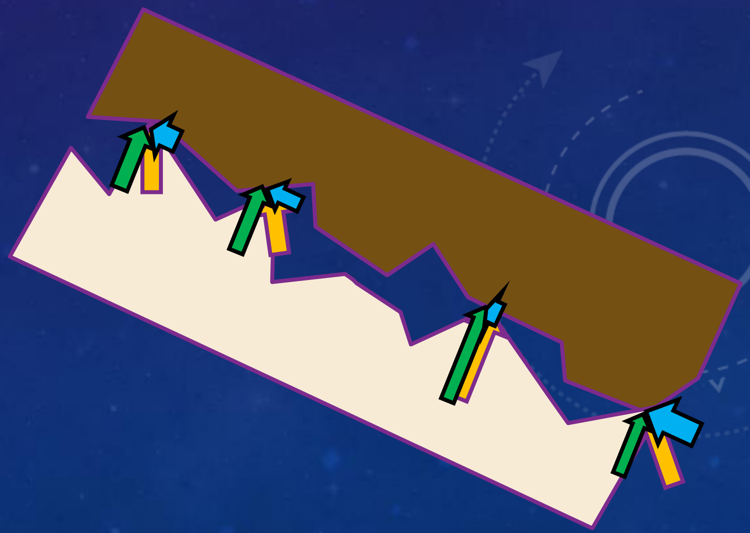
- When an object passes through a fluid, the particles of the fluid (liquid or gas) cannot pass through the object due to molecular repulsion.
- This drag force, notated F_D, depends on the relative speed (v) of the object through the fluid.
- One model that we can use is the *linear* model, which assumes that the force depends on the speed (not the speed squared, which is the *quadratic* model).
- In the linear model, the size of the force is $F_D = b * v$
  - *b* is called the drag constant, and depends on the details of the object's surface smoothness, dimensions, and angle through the fluid. Its units are N*s/m.
  - The direction is always opposite the velocity.



FRICTIONAL FORCE

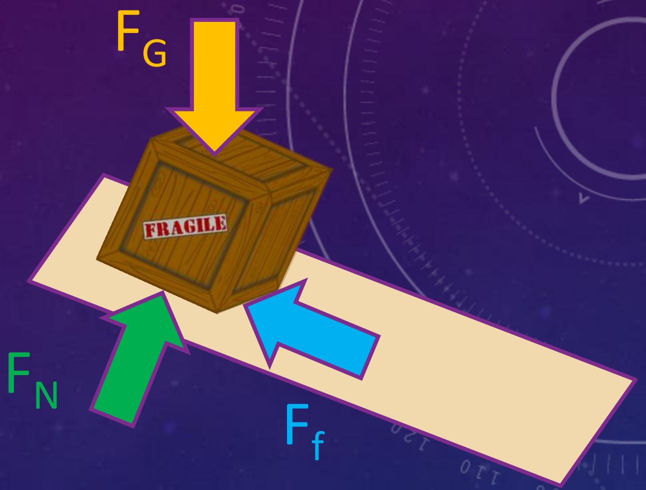
- We know from experience that friction opposes the motion of two objects sliding against each other. Friction must be a type of contact force, but is parallel to surfaces. How can this be?
  - When we look closely at two surfaces (even smooth ones) there is a microscopic roughness to them.
- As the surfaces slide against each other the peaks and valleys interact, and the contact force is not purely perpendicular to the overall surfaces; part is perpendicular, part is parallel.
  - The perpendicular part at each contact point sums up to be the normal force, F_N
  - The parallel part at each contact point sums up to be the total frictional force, F_f

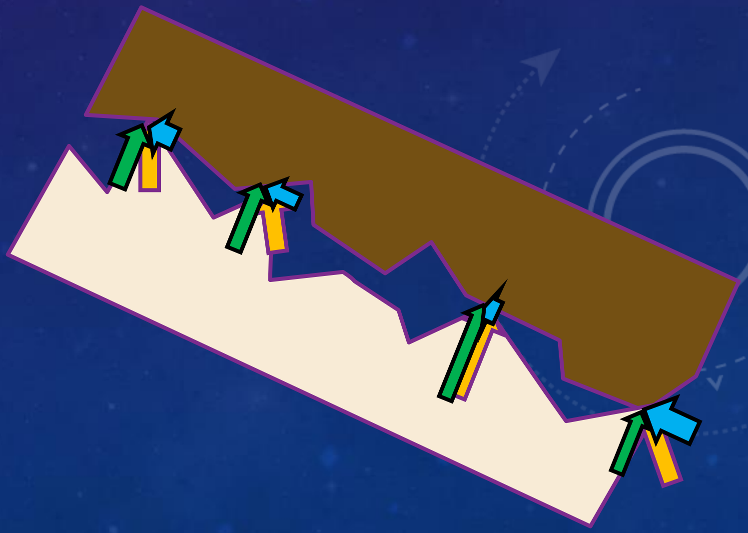




FRICTIONAL FORCE

- The size of the force depends on how hard the surfaces are pressed together (this is just the normal force) and a coefficient that captures the relative roughness of the two surfaces (the coefficient of friction, μ, called *mu*).
  - $F_f = \mu * F_N$
- The direction of the frictional force is always opposite the motion of an object (or opposite the direction it would move if friction wasn't acting on it.)
- The coefficient of friction, μ (mu), is a unitless value.





FRICTIONAL FORCE (CONTINUED)

- There are two types of friction: static friction and kinetic friction
- Static friction is acting when the surfaces are not sliding against each other
  - The surfaces are fully ‘engaged’.
  - It is similar to a car wheel in a pothole. At rest, the wheel is at the bottom of the hole. It must come all the way out of the hole, which takes more force.

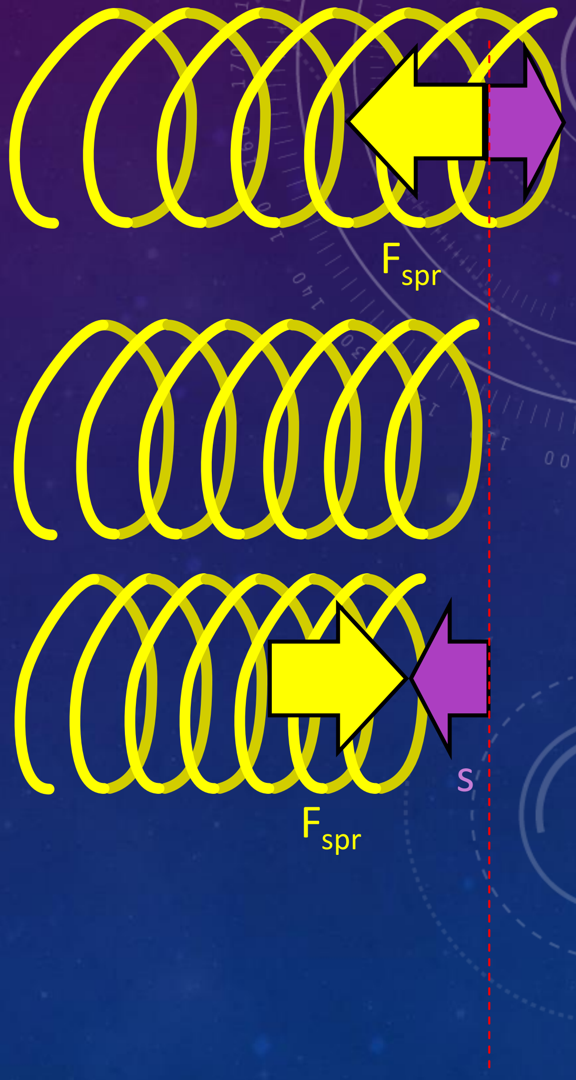
  - The surface won’t begin moving until the external force is enough to exceed the maximum ‘stickiness’ of the surfaces, F_{fsmax}.
  - $F_{fsmax} = \mu_s * F_N$

FRICTIONAL FORCE (CONTINUED)

- There are two types of friction: static friction and kinetic friction
- Kinetic friction is acting when the surfaces are sliding against each other
  - The surfaces never fully 'engage'.
  - When moving, the wheel skips across the hole, and takes less force to roll across.
  - $F_{fk} = \mu_k * F_N$
- So frictional force when moving is less than frictional force from rest, and also $\mu_k < \mu_s$.

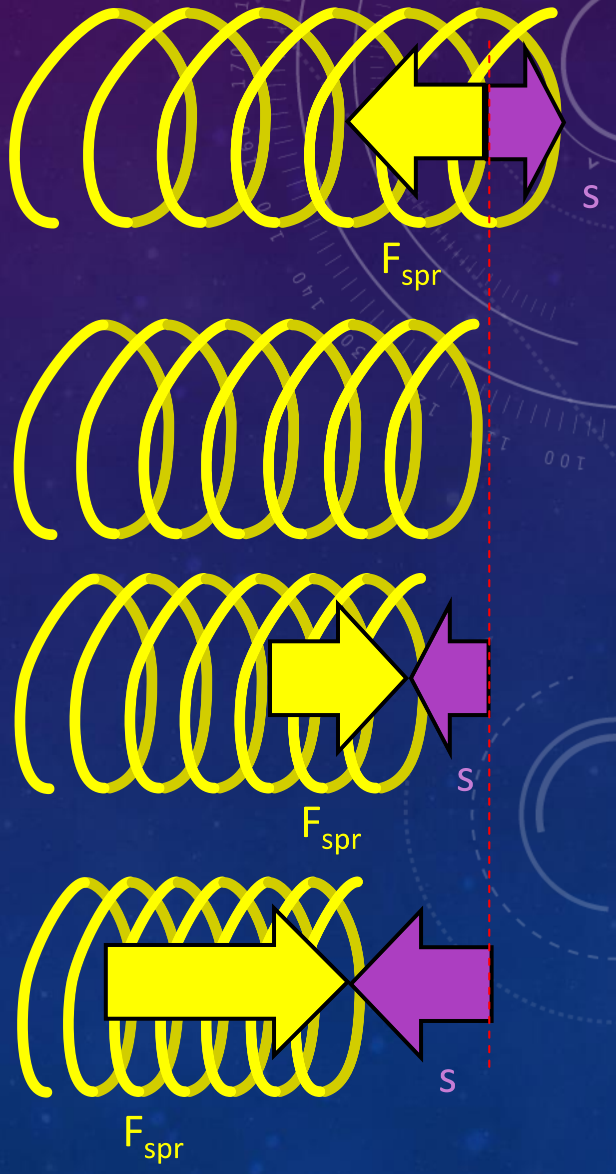
SPRING (ELASTIC) FORCE

- Solid objects have internal molecular forces that bind all the matter together. The result for this spring is that it has a natural length when no other forces act on it.
- When the object is slightly deformed, these internal forces try to restore the original shape.
- Usually, the restoring spring force is the same whether you compress or stretch the object.
- For most objects when they are only slight deformed, the force depends on the amount of deformation (called *s* here) and how 'springy' the object is (the spring constant, called *k* here).



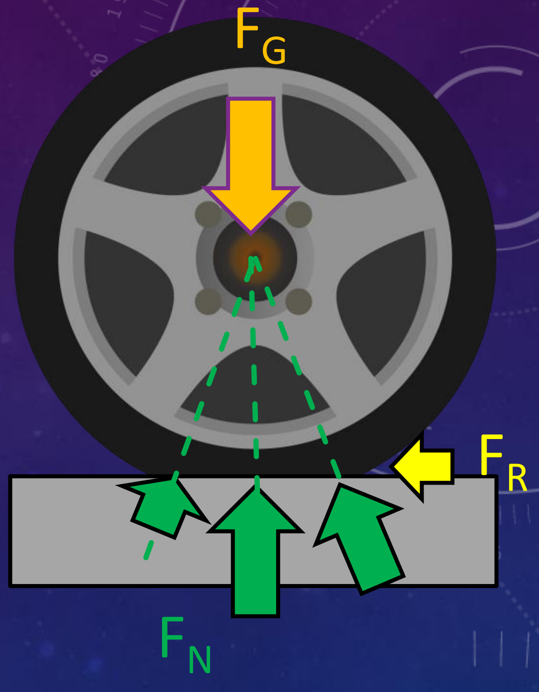
SPRING (ELASTIC) FORCE

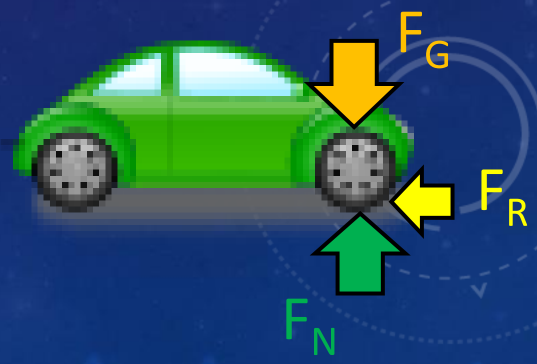
- We can use the linear model:
  - The size of the force is $F_{spr} = k * s$
  - The direction of the spring force is opposite the direction of the deformation, *s*. (It is a *restoring* force.)
- If we double the compression, the spring force doubles in response.
- The units of the spring constant are N/m.



ROLLING RESISTANCE

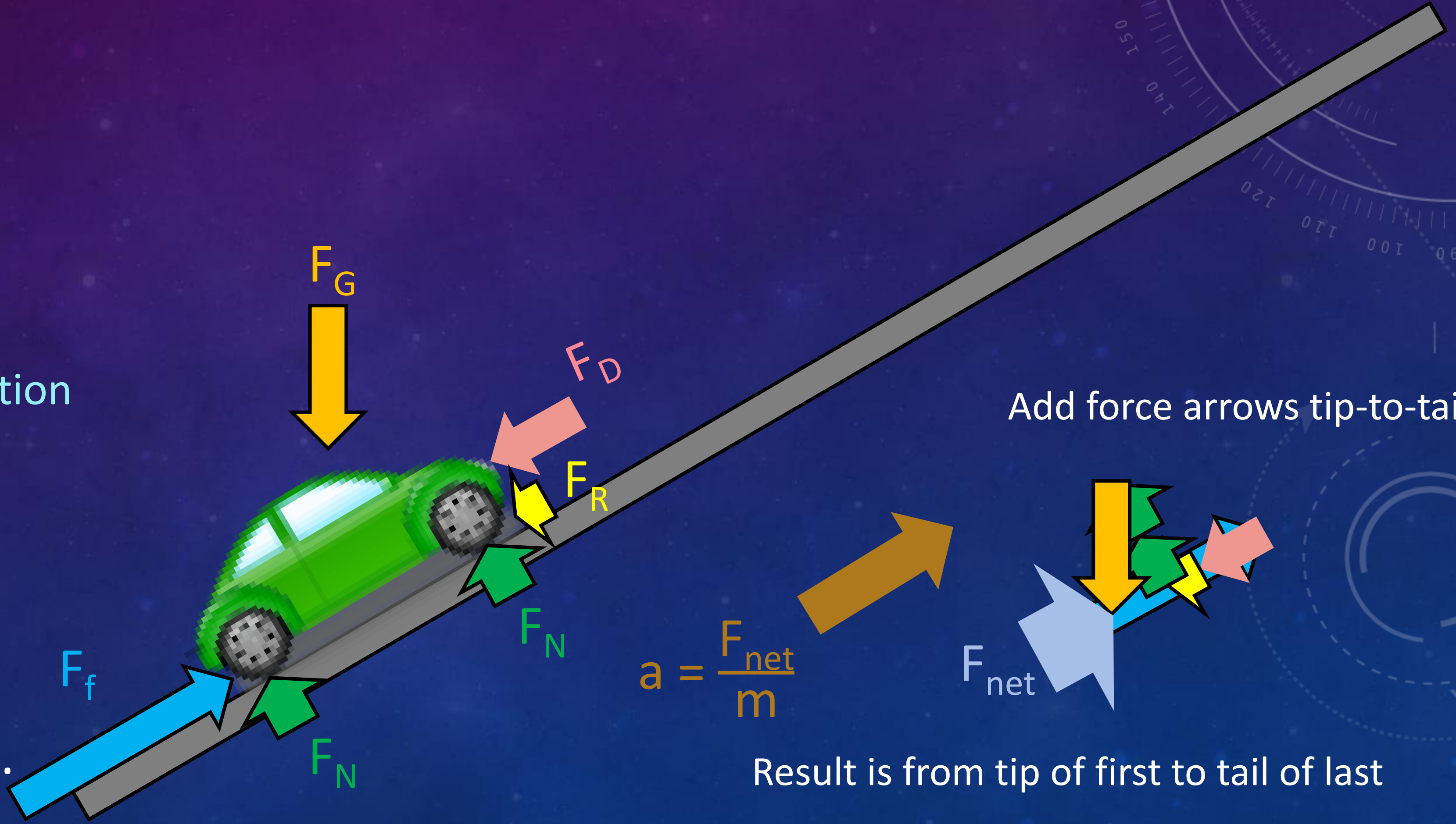
- Tires are spring-like; when compressed under the weight of a vehicle, they push back.
- As a tire rolls forward, the weight compresses the front part of the tire, which pushes back.
- The back part of the tire pushes forward a little as the tire leaves the ground.
- The springiness of the tire doesn't return quite all of the effort it took to compress them. The net effect is called *rolling resistance* which is opposite the rolling direction.
- We don't have a particular model for rolling resistance; we typically just measure it or calculate it from Newton's Laws.
- Rolling resistance depends on the springiness of both the tire and the surface on which it rolls (road, dirt, sand, etc.)
- Steel wheels are very stiff and have little deformation. This is why trains use steel wheels on steel rails. They experience very little rolling resistance.





EXAMPLE: CAR ACCELERATING UP A HILL

- The forces in this example include:
  - Gravity
  - Fluid drag
  - Normal force
  - Drive wheel static friction
  - Rolling resistance
- The net force must be up, along the hill, because the car accelerates up the hill.



CONCLUSION

- It helps to draw a picture of the object of interest isolated from its environment (the free-body diagram.)
- Draw all of the forces acting on it from the environment, including the direction of each.
- Add the force vectors, including both their size and direction.
- Acceleration is that resulting force divided by the object's mass.
- Once acceleration is known, velocity and position can be found from it.
- Force models can be made more sophisticated, but these give a good sense of how these forces behave.