DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
AP PHYSICS

LSN 4-8: PROBLEMS INVOLVING FRICTION AND INCLINES
LSN 4-9: PROBLEM SOLVING PROCESS

Big Idea(s):

- Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
- Big Idea 2: Fields existing in space can be used to explain interactions.

Big Idea(s):

- Big Idea 3: The interactions of an object with other objects can be described by forces.
- Big Idea 4: Interactions between systems can result in changes in those systems.

Enduring Understanding(s):

- 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- 2.B: A gravitational field is caused by an object with mass.
- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.

Enduring Understanding(s):

- 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $a = \frac{F}{m}$
- 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

Enduring Understanding(s):

- 3.G: Certain types of forces are considered fundamental.
- 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where

$$\vec{a} = \frac{\vec{F}}{m}$$

Essential Knowledge(s):

- 1.C.1: Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems.

Essential Knowledge(s):

- 2.B.1: A gravitational field at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.
  - On the Earth, this gravitational force is called weight.
  - The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
  - If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in newtons/kilogram) at that location.

Essential Knowledge(s):

- 3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
  - Displacement, velocity, and acceleration are all vector quantities.
  - Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.
  - A choice of reference frame determines the direction and the magnitude of each of these quantities.

Essential Knowledge(s):

- 3.A.3: A force exerted on an object is always due to the interaction of that object with another object.
  - An object cannot exert a force on itself.
  - Even though an object is at rest, there may be forces exerted on that object by other objects.
  - The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

Essential Knowledge(s):

- 3.A.2: Forces are described by vectors.
  - Forces are detected by their influence on the motion of an object.
  - Forces have magnitude and direction.
- 3.A.4: If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

Essential Knowledge(s):

- 3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- 3.C.4: Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).

Essential Knowledge(s):

- 3.G.1: Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.
- 4.A.3: Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

Learning Objective(s):

- (1.C.1.1): The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
- (2.B.1.1): The student is able to apply to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems.
- (3.A.1.1): The student is able to express the motion of an object using narrative, mathematical, and graphical representations.

Learning Objective(s):

- (3.A.1.2): The student is able to design an experimental investigation of the motion of an object.
- (3.A.1.3): The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations.
- (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.

Learning Objective(s):

- (3.A.3.1): The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces.
- (3.A.4.1): The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces.
- (3.A.4.2): The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact.

Learning Objective(s):

- (3.B.1.1): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension.
- (3.B.1.2): The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.

Learning Objective(s):

- (3.B.1.4): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations.
- (3.C.4.1): The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces.

Learning Objective(s):

- (3.C.4.2): The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions.
- (3.G.1.1): The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.

Learning Objective(s):

- (4.A.3.1): The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system.

FINALLY!

Friction - Microscopic

- Even when two surfaces appear smooth, at the microscopic level they will appear jagged
- The jagged edges of the two surfaces interlock and a force must be applied to lift the body up and over the interlock
- Once the body is moving, it tends to bounce from peak to peak on top of the jagged edges so less force is required

Friction - Intermolecular

- When two objects are in contact, intermolecular forces create a binding of the two
- A force greater than the binding force must be applied to break the bond

Friction – Two Categories

- ***Static Friction*** – when the two bodies that are in contact with each other ***are not moving*** in relation to each other
- ***Kinetic Friction*** – when two bodies in contact with each other ***are moving*** in relation to each other
- Static friction ≥ kinetic friction
- Place a book on your table and apply an increasing force with one finger
  - Notice how it "pops" when it starts to move

Coefficient of Friction

- A unitless number that reflects the relative smoothness between two surfaces
- The value will vary with every type of material
- There are separate values for static and kinetic friction
- The variable used to represent the coefficient of friction is the lowercase Greek letter mu, μ

Friction – Two Categories

- See Table 4-2 for representative values of coefficients of friction
- $\mu_s \geq \mu_k$

Force of Friction

- The Force of Friction is equal to the normal force times the coefficient of friction

$$F_f = F_N \mu$$

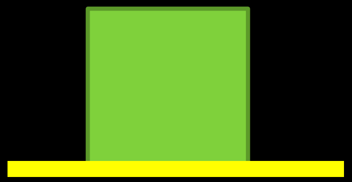
- Remember that the normal force is the contact or resistant force that acts *perpendicular to* (normal to) the contact surface
  - Newton's Third Law

Force of Friction

- The Force of Friction is a resistance force which means it will ***oppose motion***, but ***cannot cause an object to move***
- The direction of the force of friction will always be in the opposite direction of the motion (kinetic friction) or the intended motion (static friction)

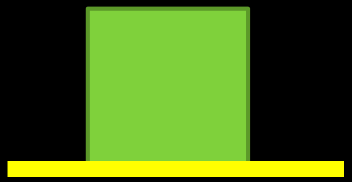
Sample Problem

- What minimum force is required to start a 10-kg wooden box moving across a wooden floor?



Sample Problem

- What minimum force is required to start a 10-kg wooden box moving across a wooden floor?
  - Find the coefficient of friction from Table 4-2.



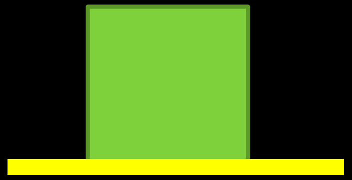
Sample Problem

- What minimum force is required to start a 10-kg wooden box moving across a wooden floor?

$$m = 10kg$$

$$\mu_s = 0.4$$

$$g = 9.81m/s^2$$



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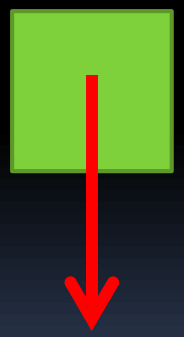

$F_w = mg$

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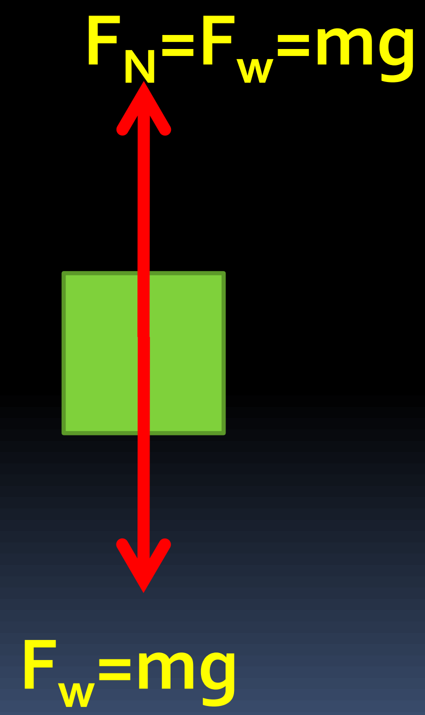

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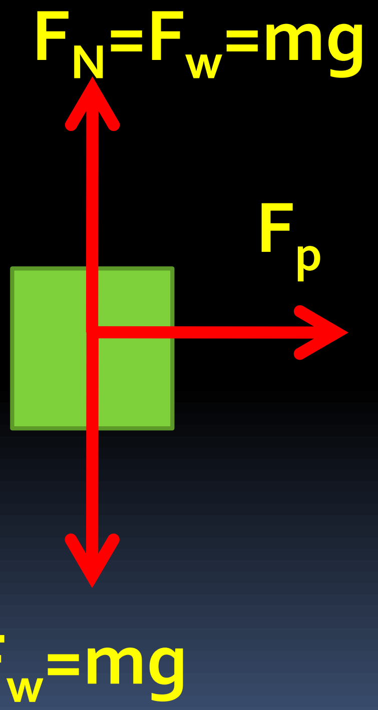

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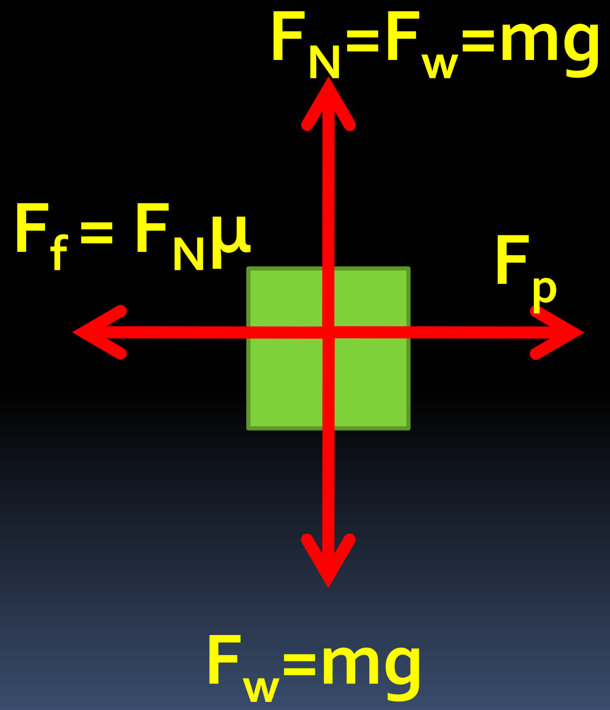
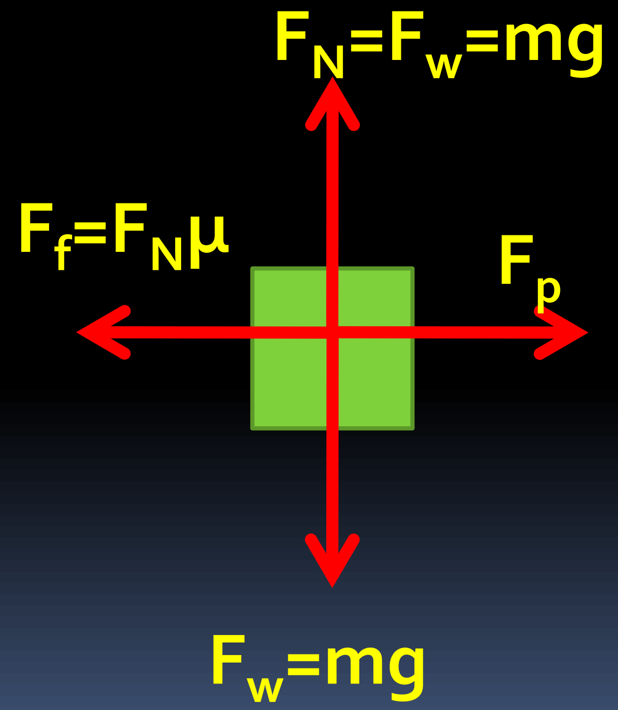


Sample Problem

- What minimum force is required to start a 10-kg wooden box moving across a wooden floor?

$$\sum F_x = ma_x$$
$$F_p - F_f = 0$$
$$F_p = F_f$$
$$F_p = F_N \mu$$
$$F_p = mg\mu = 39.2N$$

$$m = 10kg$$
$$\mu_s = 0.4$$
$$g = 9.81 m/s^2$$
$$a = 0$$



Sample Problem 2

If you push a 10kg wooden box across a wooden floor with a 50N force, how fast will it be going after 5 sec?

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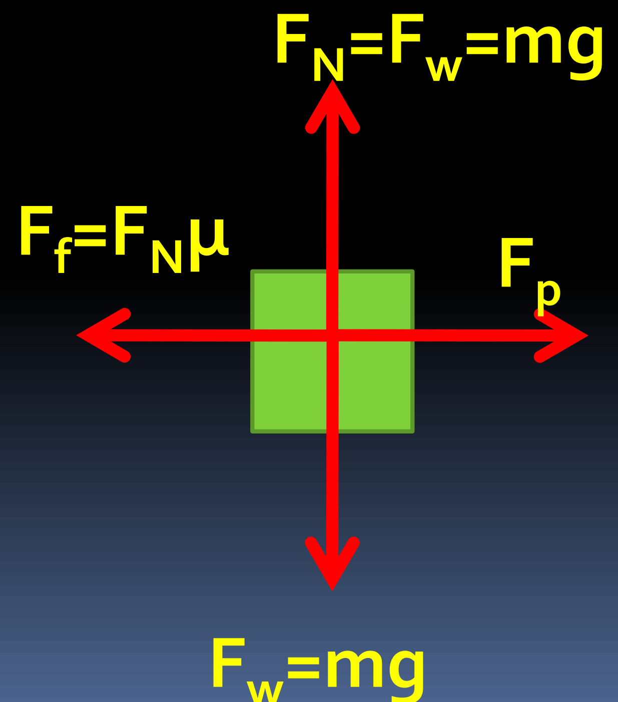


Sample Problem 2

If you push a 10kg wooden box across a wooden floor with a 50N force, how fast will it be going after 5 sec?

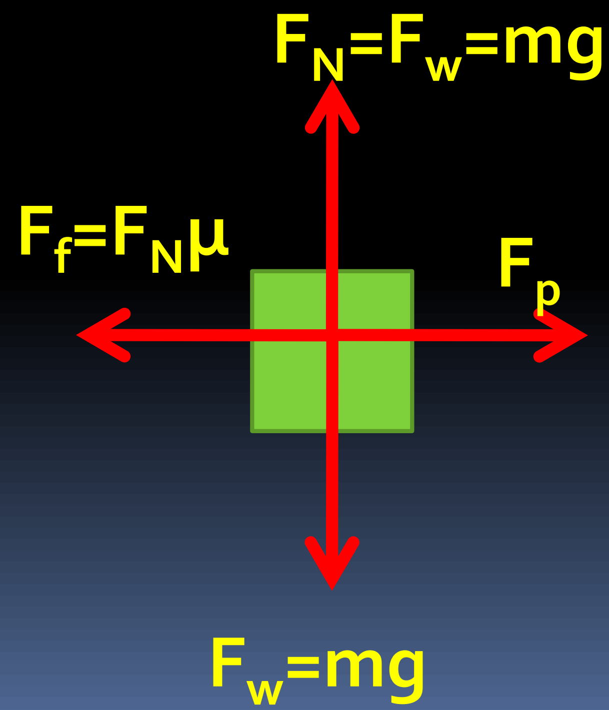
$$m = 10kg$$

$$\mu_k = 0.2$$

$$g = 9.81 m/s^2$$

$$F_p = 50N$$

$$t = 5\sec$$



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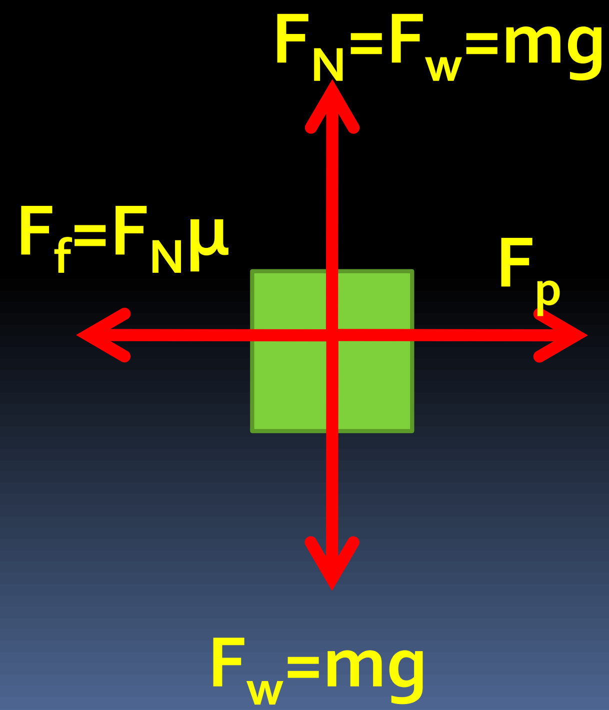
$$F_p = 50N$$
$$t = 5\sec$$

$$\sum F = ma$$
$$F_p - F_f = ma$$
$$F_f = F_N \mu_k = mg\mu_k$$
$$F_p - mg\mu_k = ma$$
$$\frac{F_p - mg\mu_k}{m} = a$$



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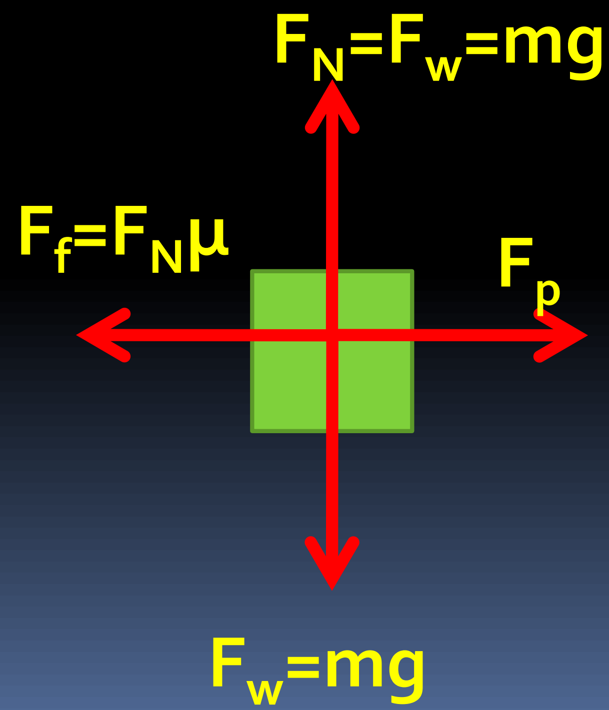

$$\frac{F_p - mg\mu_k}{m} = a$$

$$\frac{(50)-(10)(9.81)(0.2)}{10} = a = 3.04 m/s^2$$

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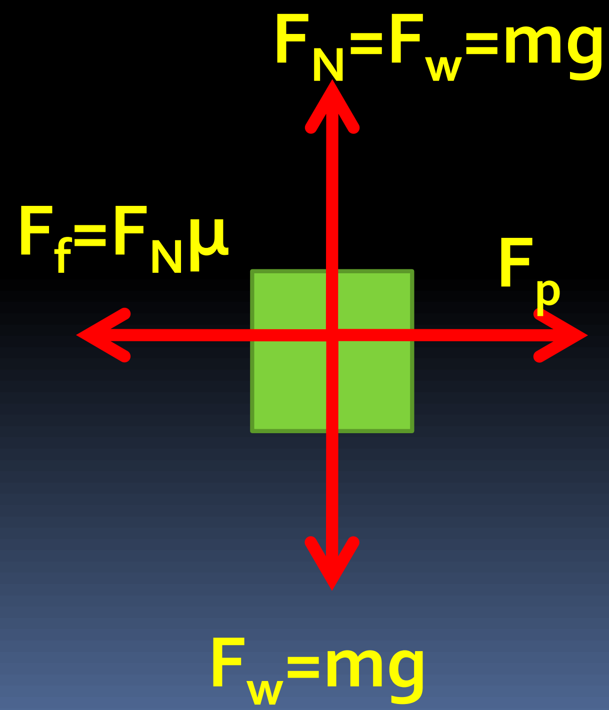
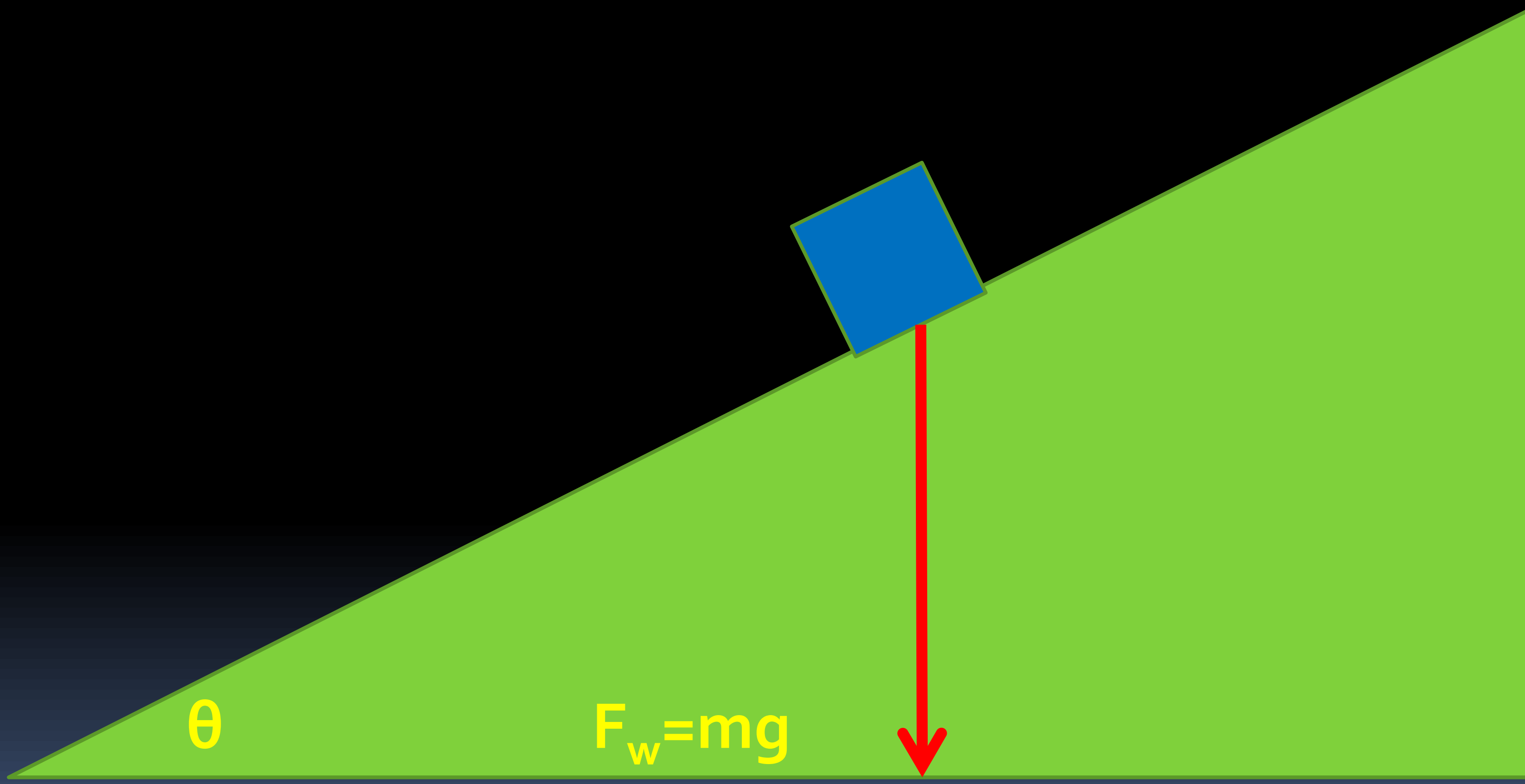
$$g = 9.81 m/s^2$$
$$F_p = 50N$$
$$t = 5\sec$$

$$a = 3.04 m/s^2$$
$$a = \frac{\Delta v}{\Delta t}$$
$$\Delta v = a\Delta t$$
$$\Delta v = (3.04)(5) = 15.2 m/s$$



Inclined Plane



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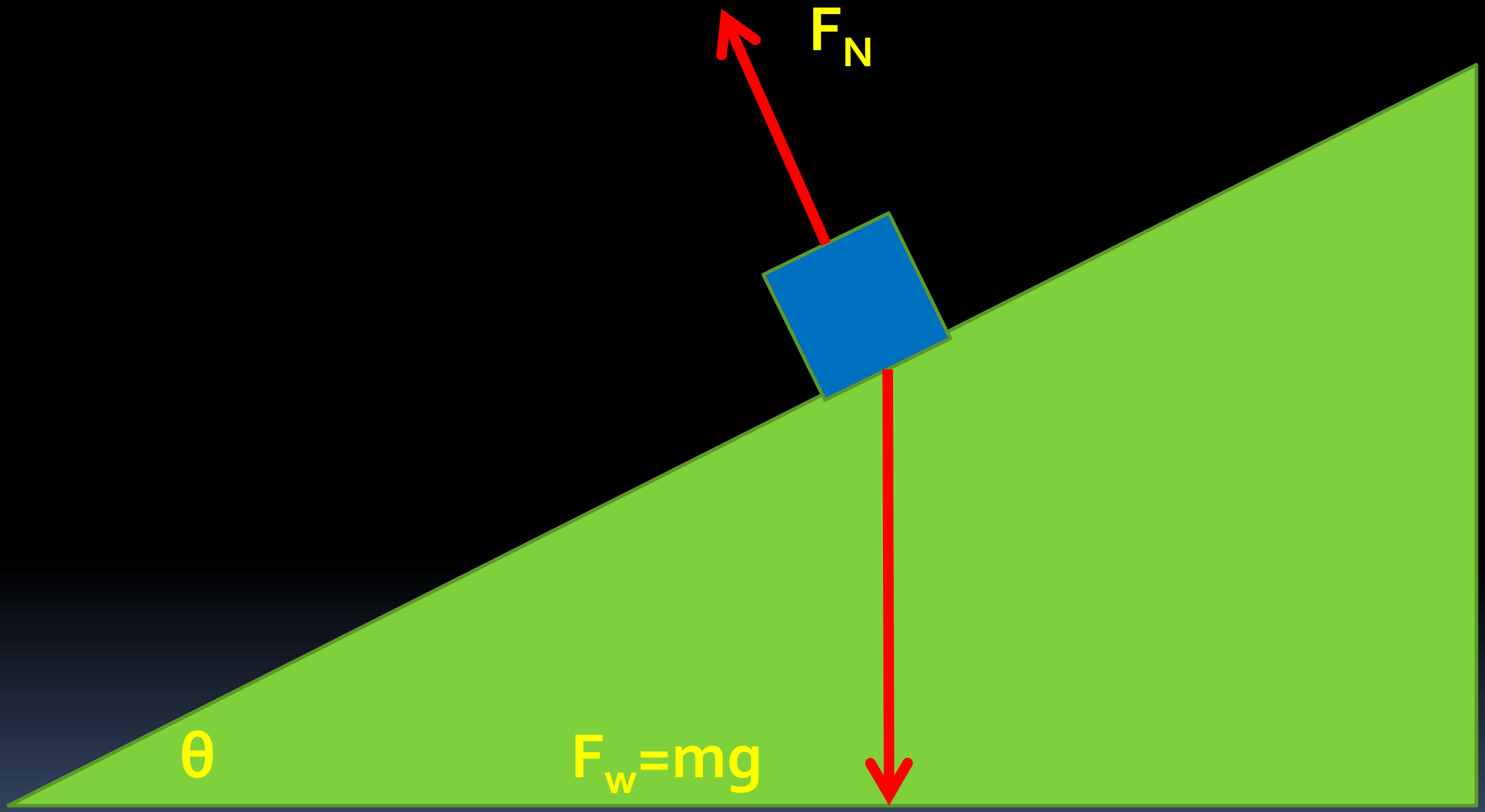

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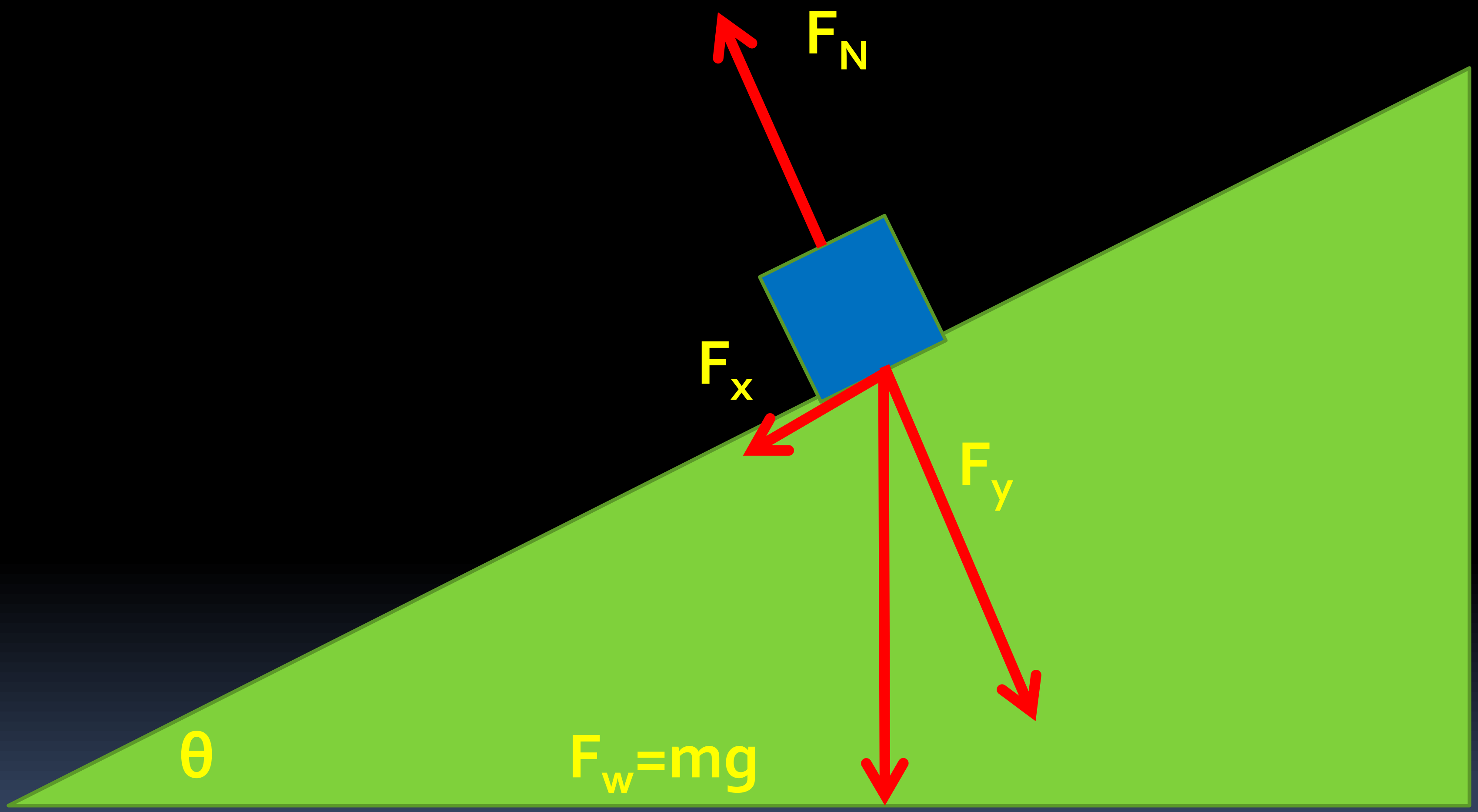

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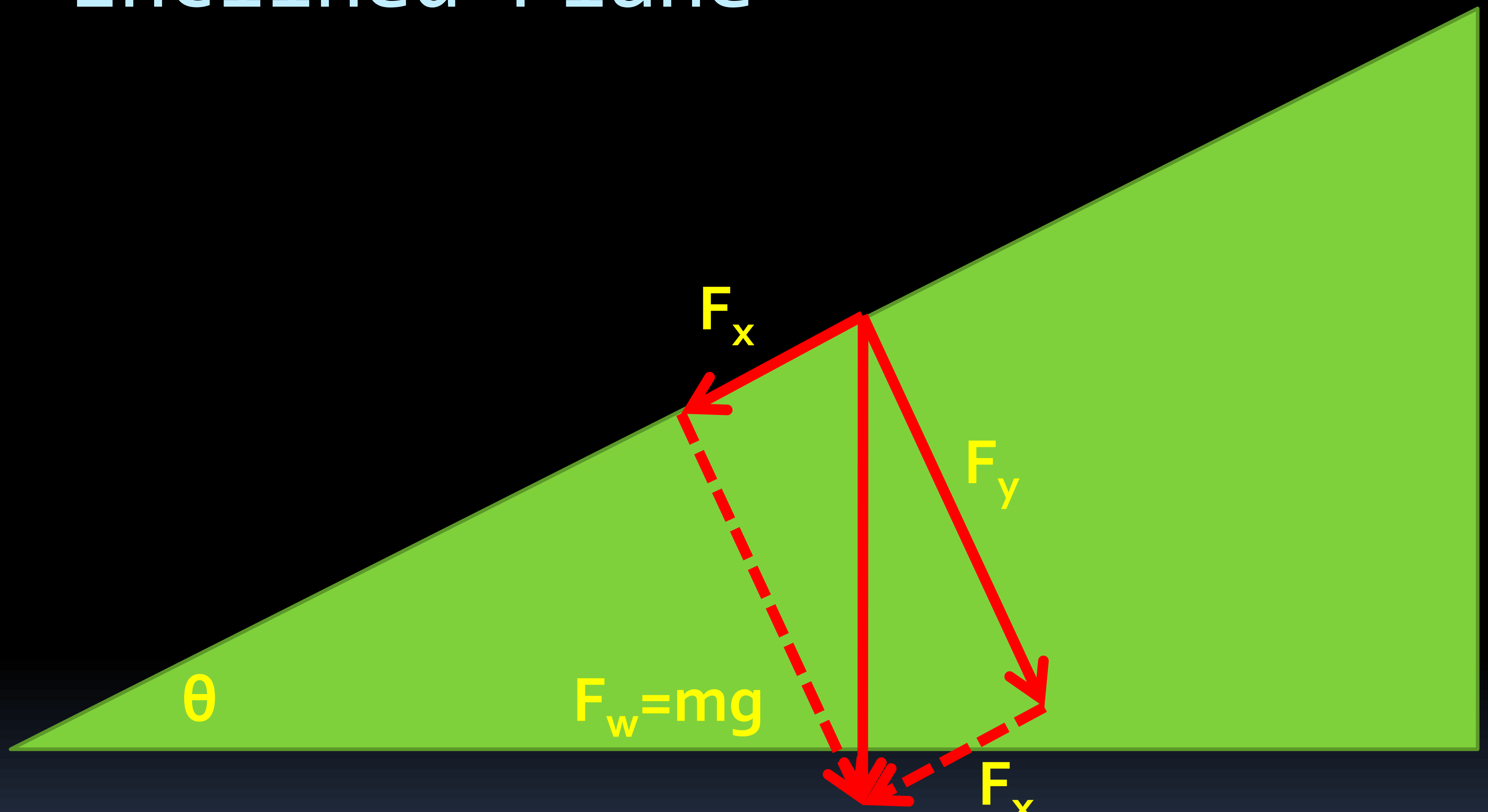

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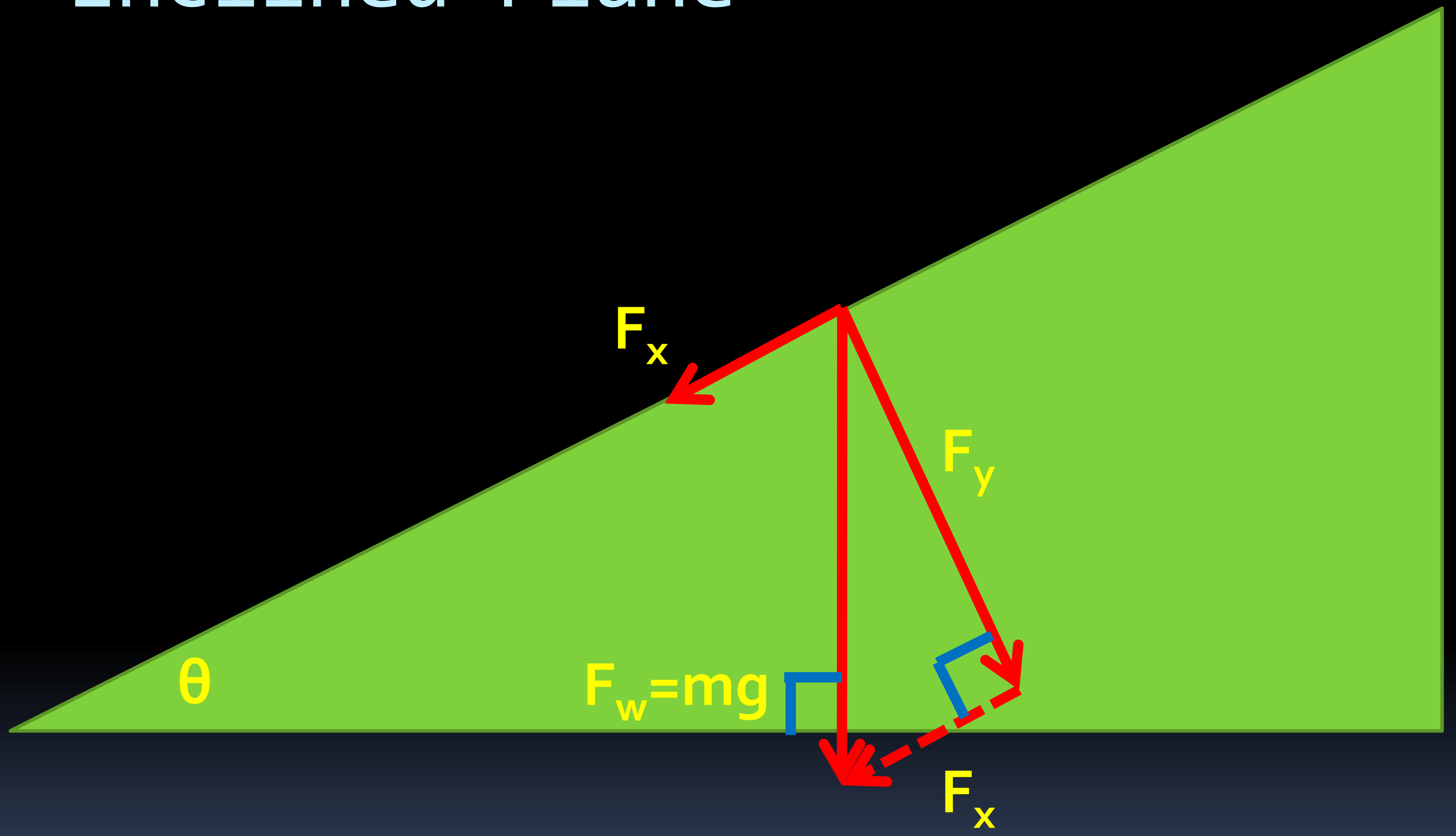

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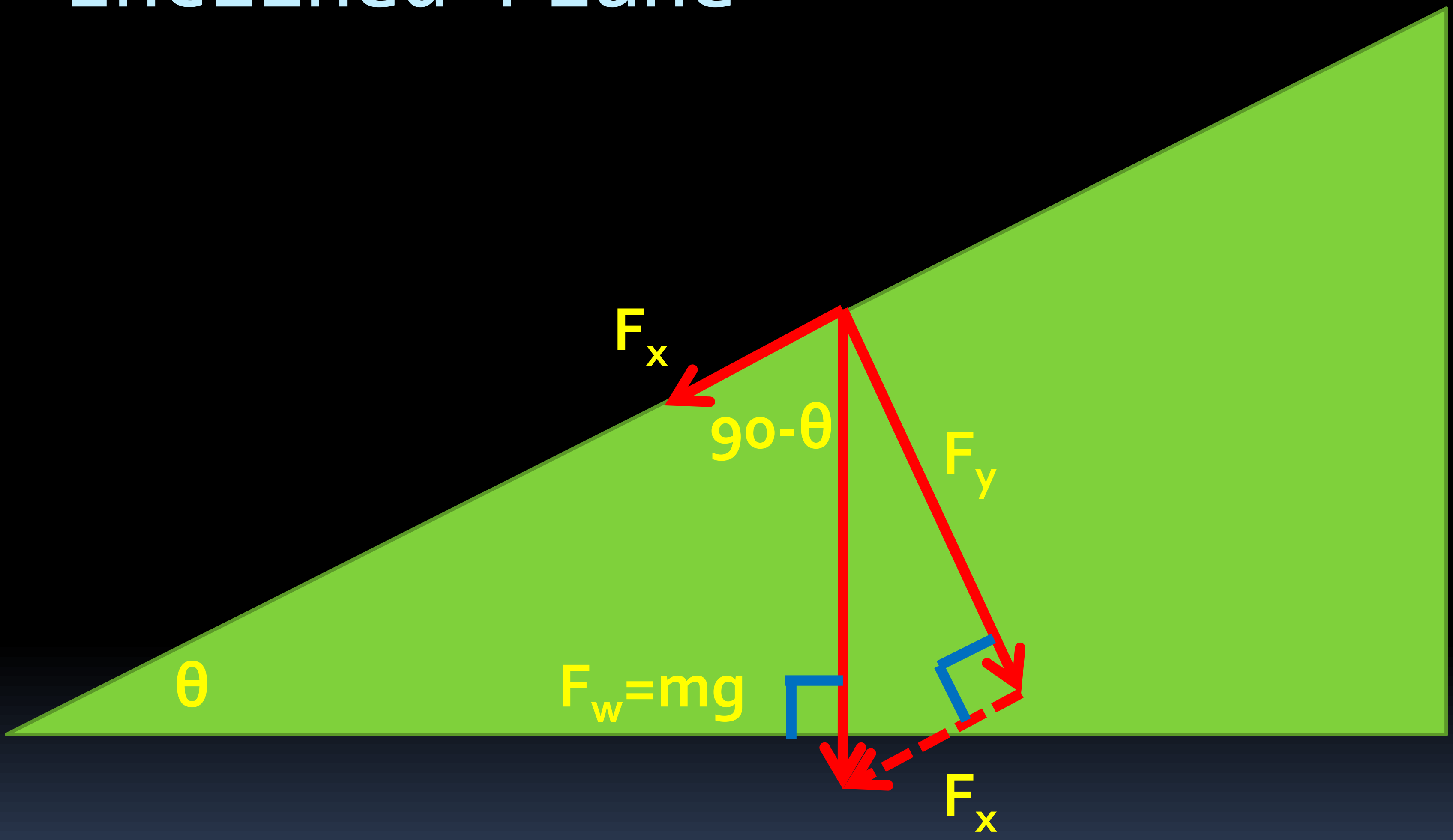

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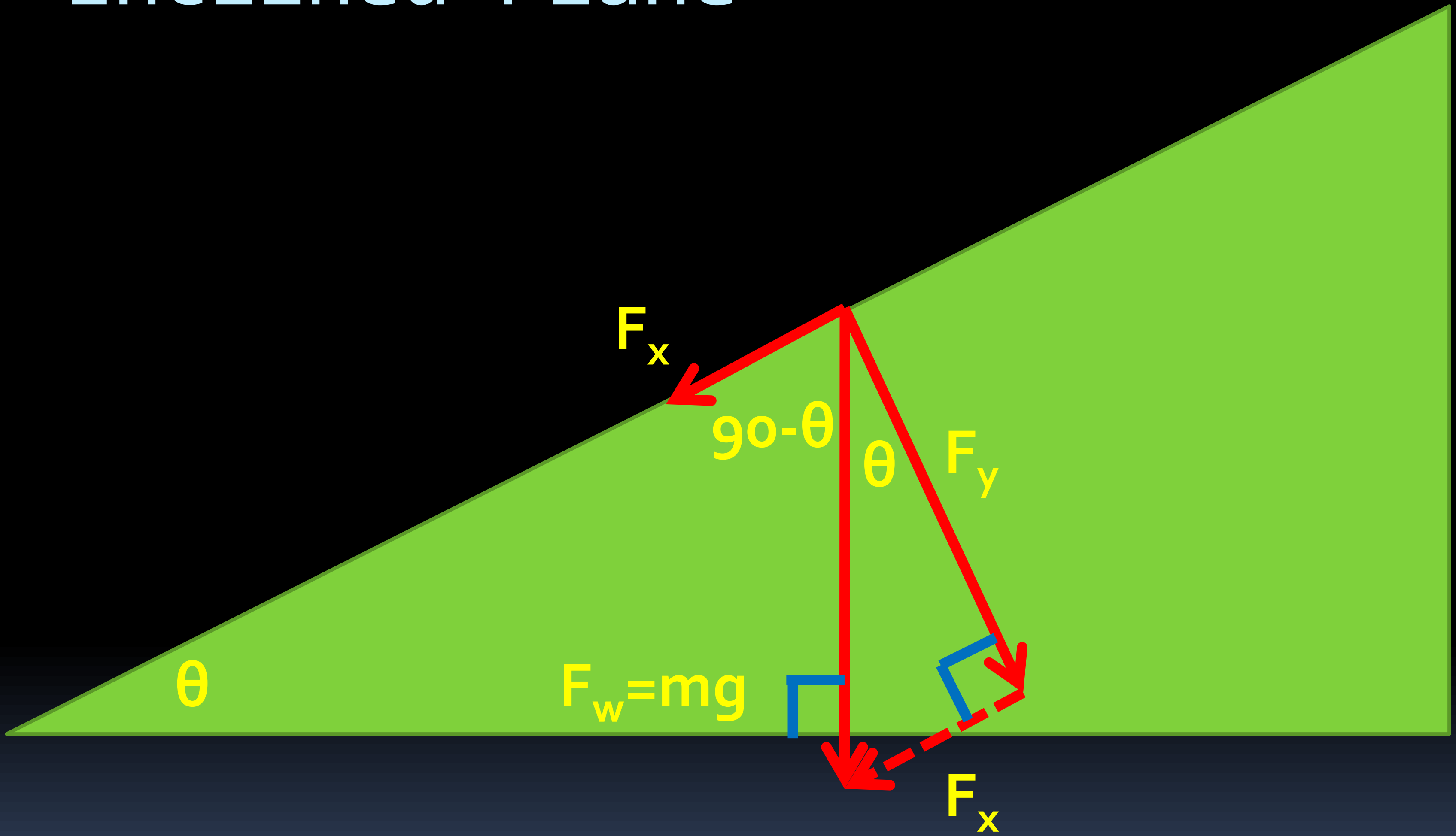


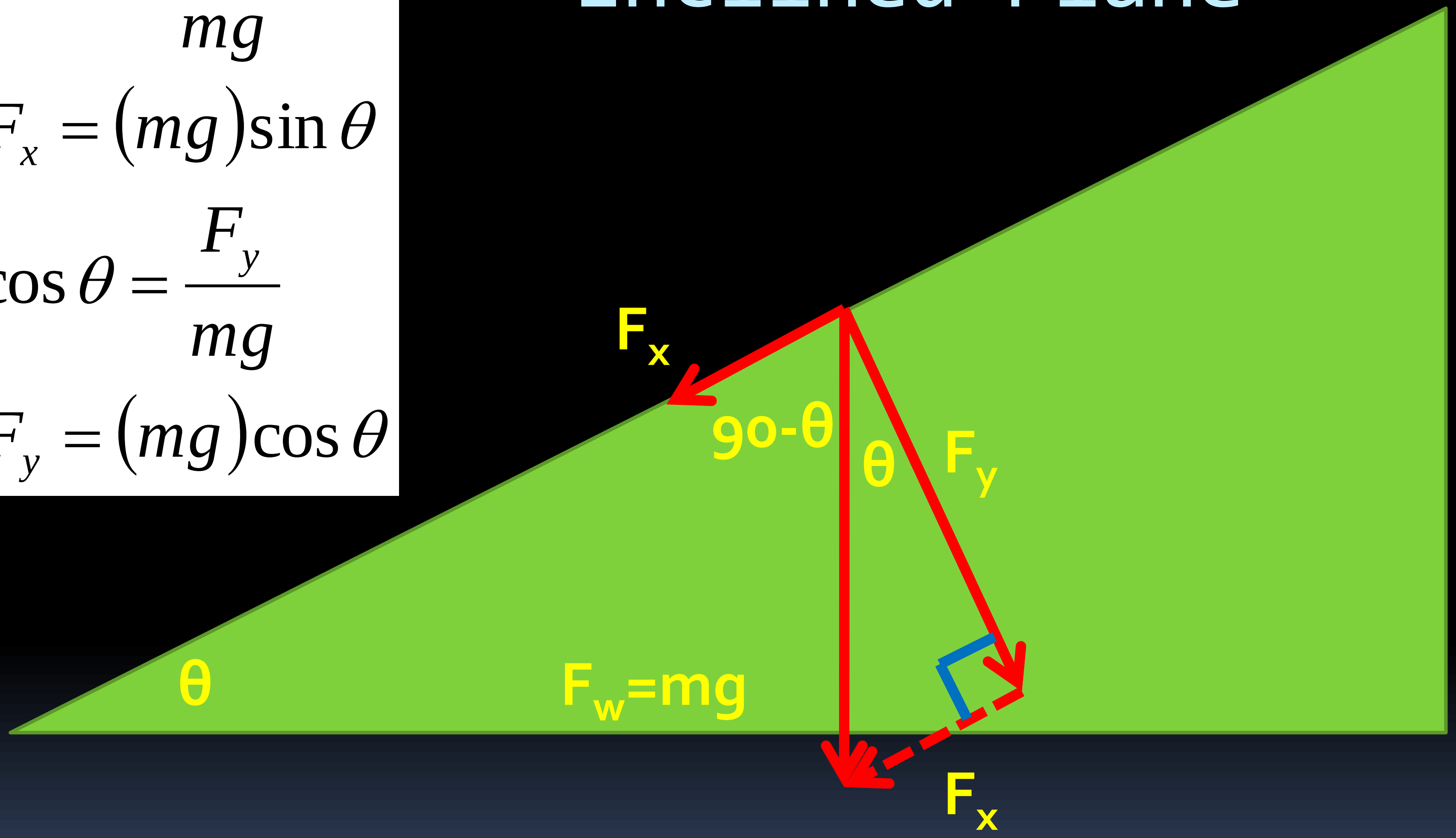
Inclined Plane

$$\sin\theta = \frac{F_x}{mg}$$

$$F_x = (mg)\sin\theta$$

$$\cos\theta = \frac{F_y}{mg}$$

$$F_y = (mg)\cos\theta$$



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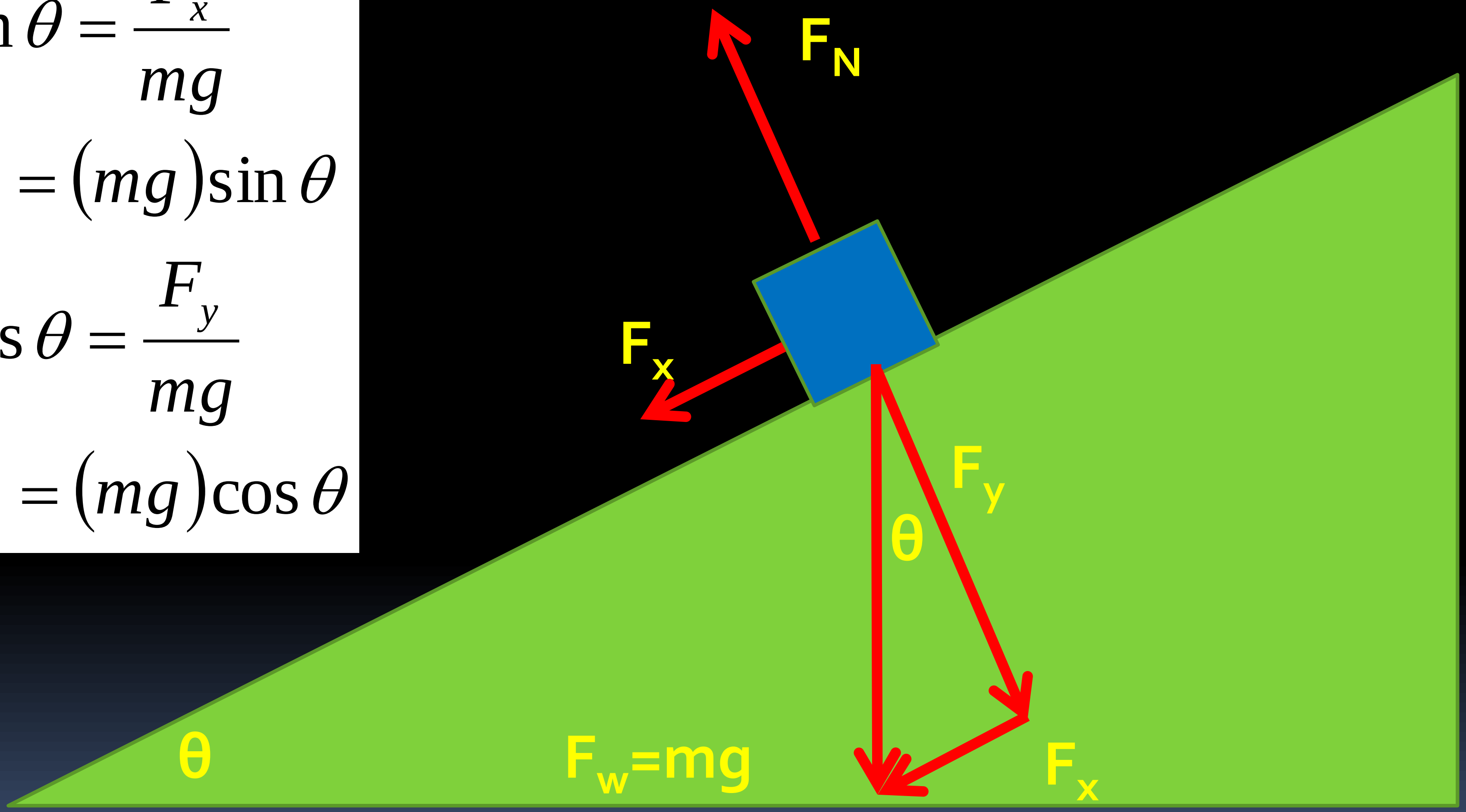

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$$F_x = (mg)\sin\theta$$

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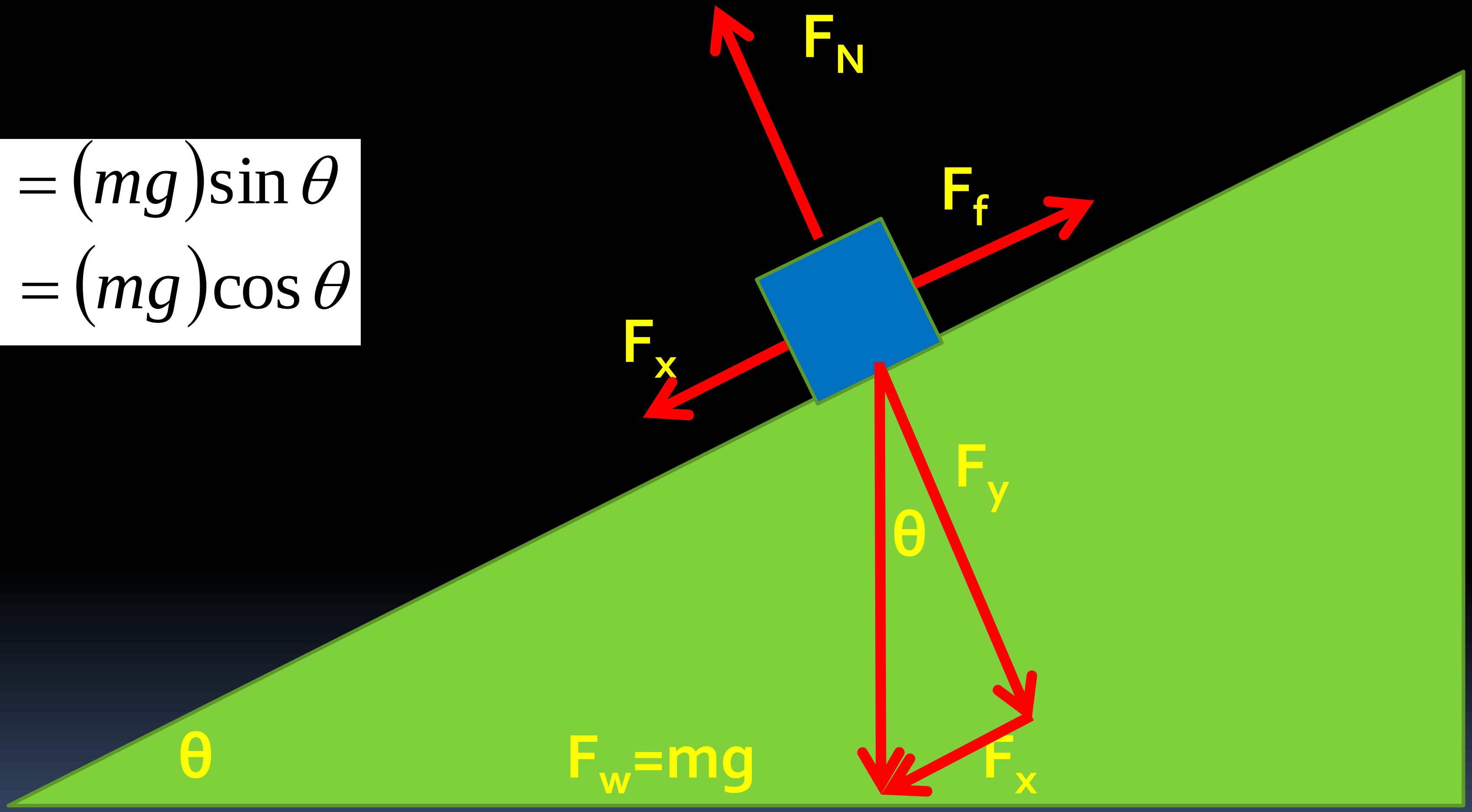
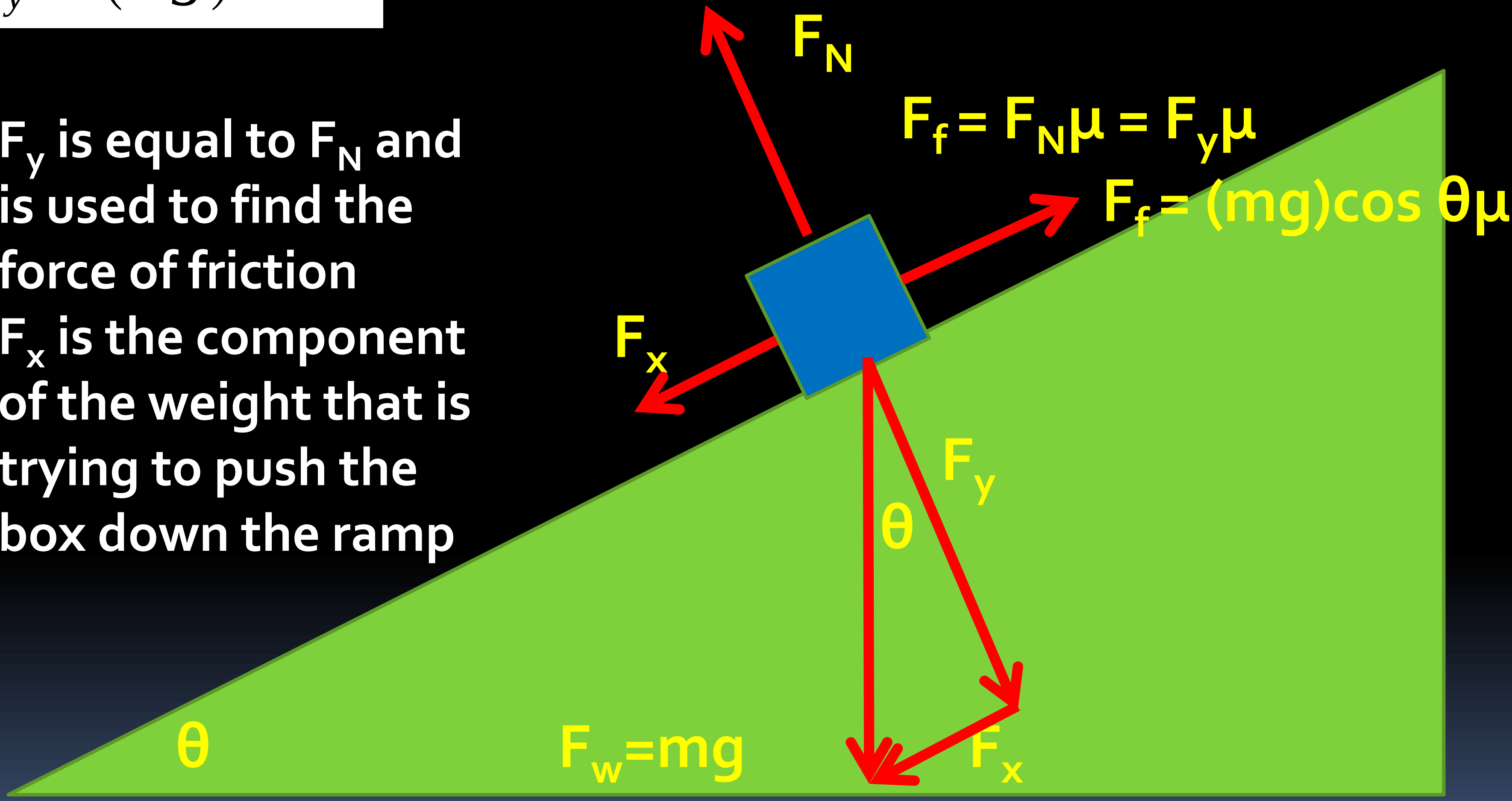


$$F_x = (mg)\sin\theta$$
$$F_y = (mg)\cos\theta$$

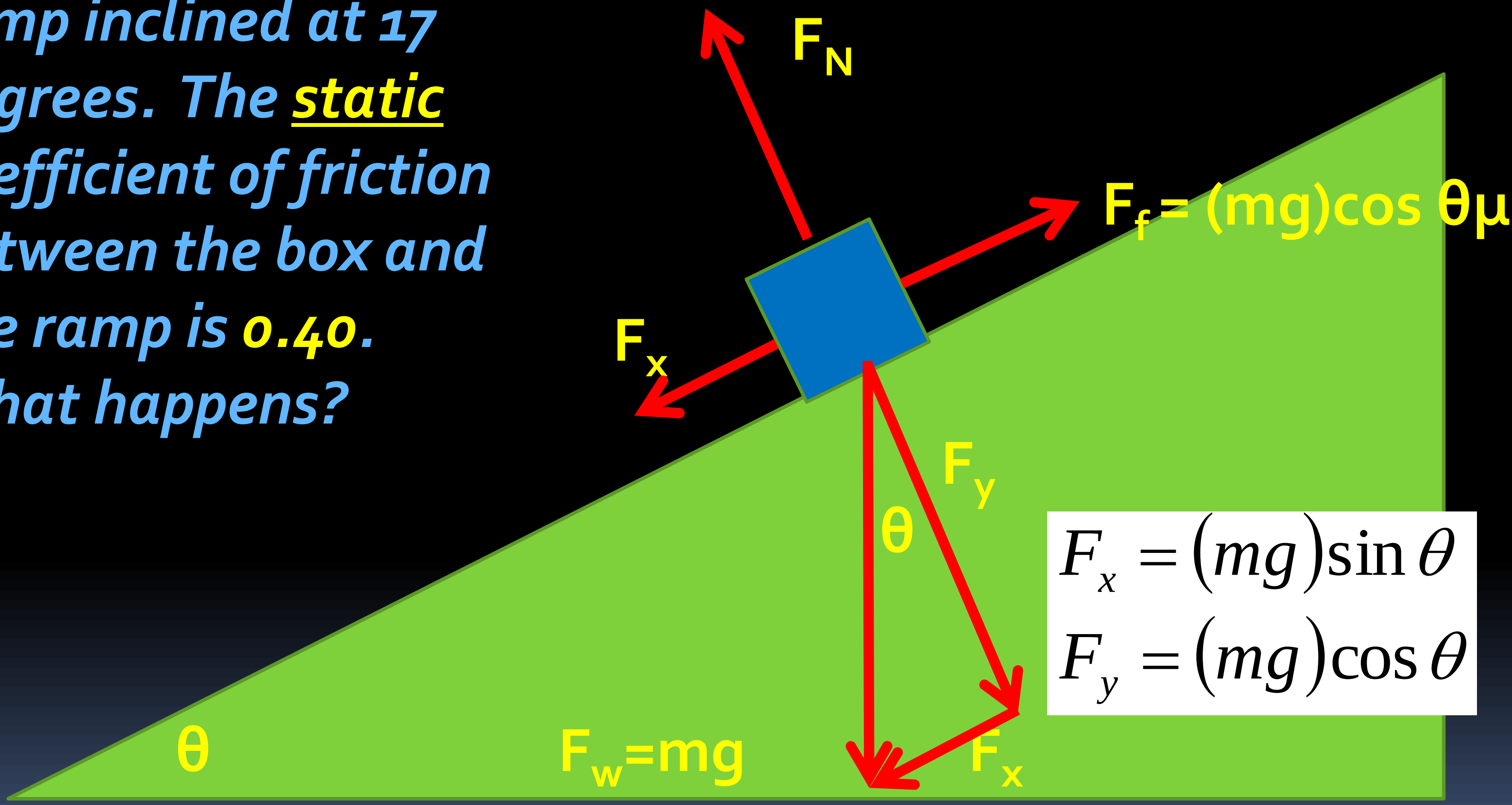
Inclined Plane

- F_y is equal to F_N and is used to find the force of friction
- F_x is the component of the weight that is trying to push the box down the ramp



Inclined Plane

*A 10kg box sits on a ramp inclined at 17 degrees. The **static** coefficient of friction between the box and the ramp is **0.40**. What happens?*



Inclined Plane

$$F_y = F_N$$

$$F_f = F_N \mu = (mg)\cos\theta\mu$$

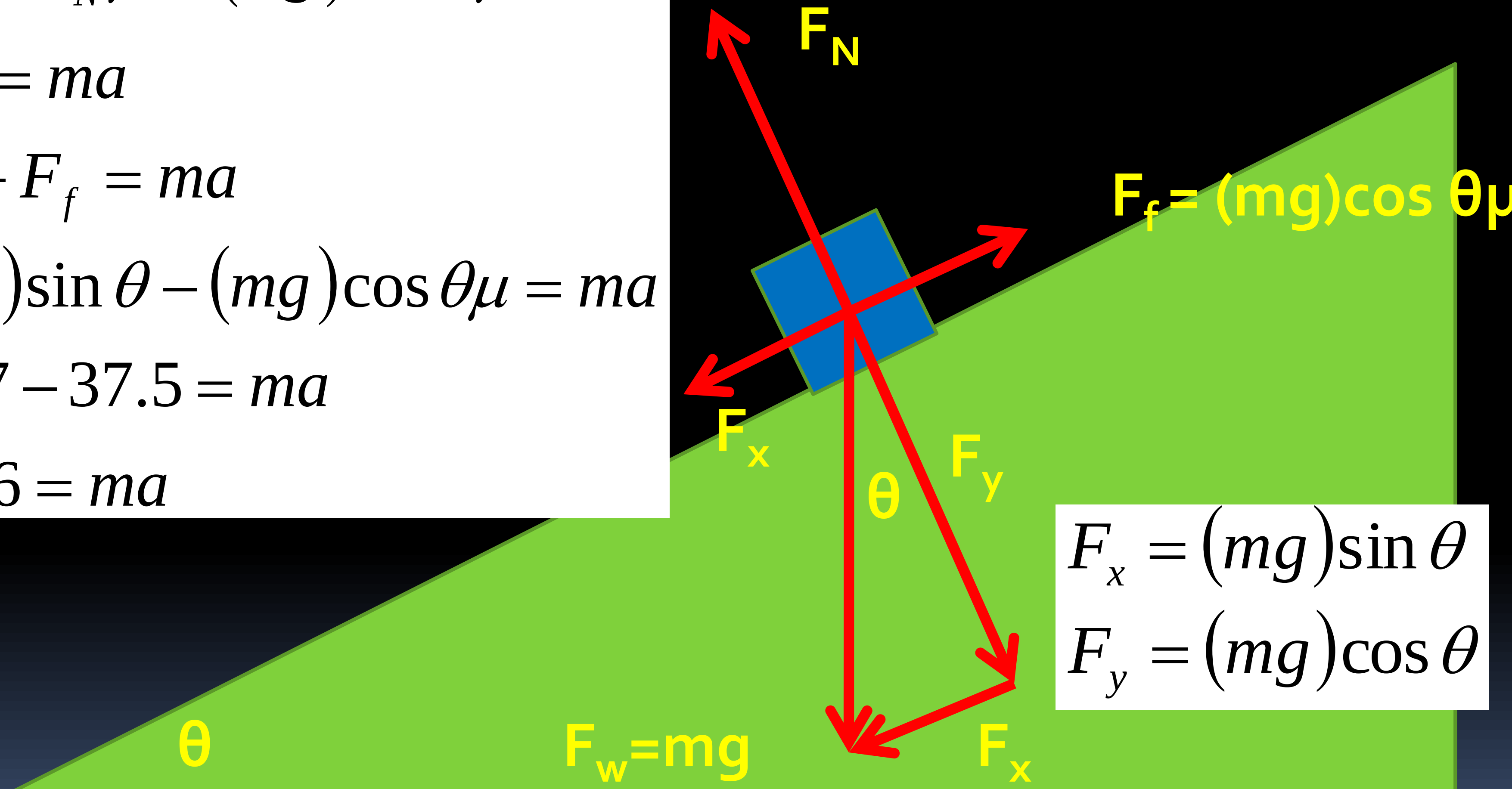
$$\Sigma F = ma$$

$$F_x - F_f = ma$$

$$(mg)\sin\theta - (mg)\cos\theta\mu = ma$$

$$28.7 - 37.5 = ma$$

$$-8.6 = ma$$



$$F_x = (mg)\sin\theta$$

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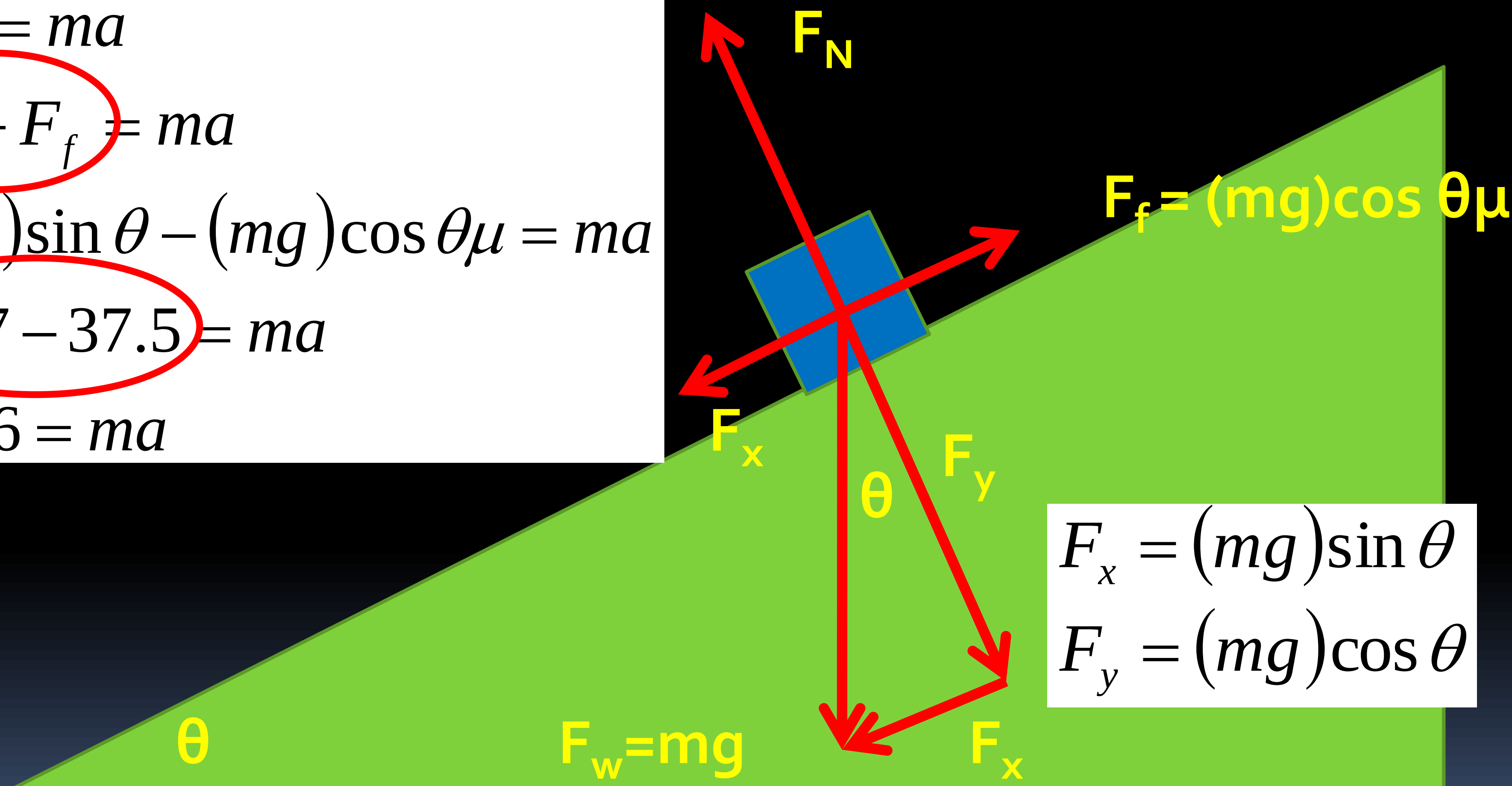


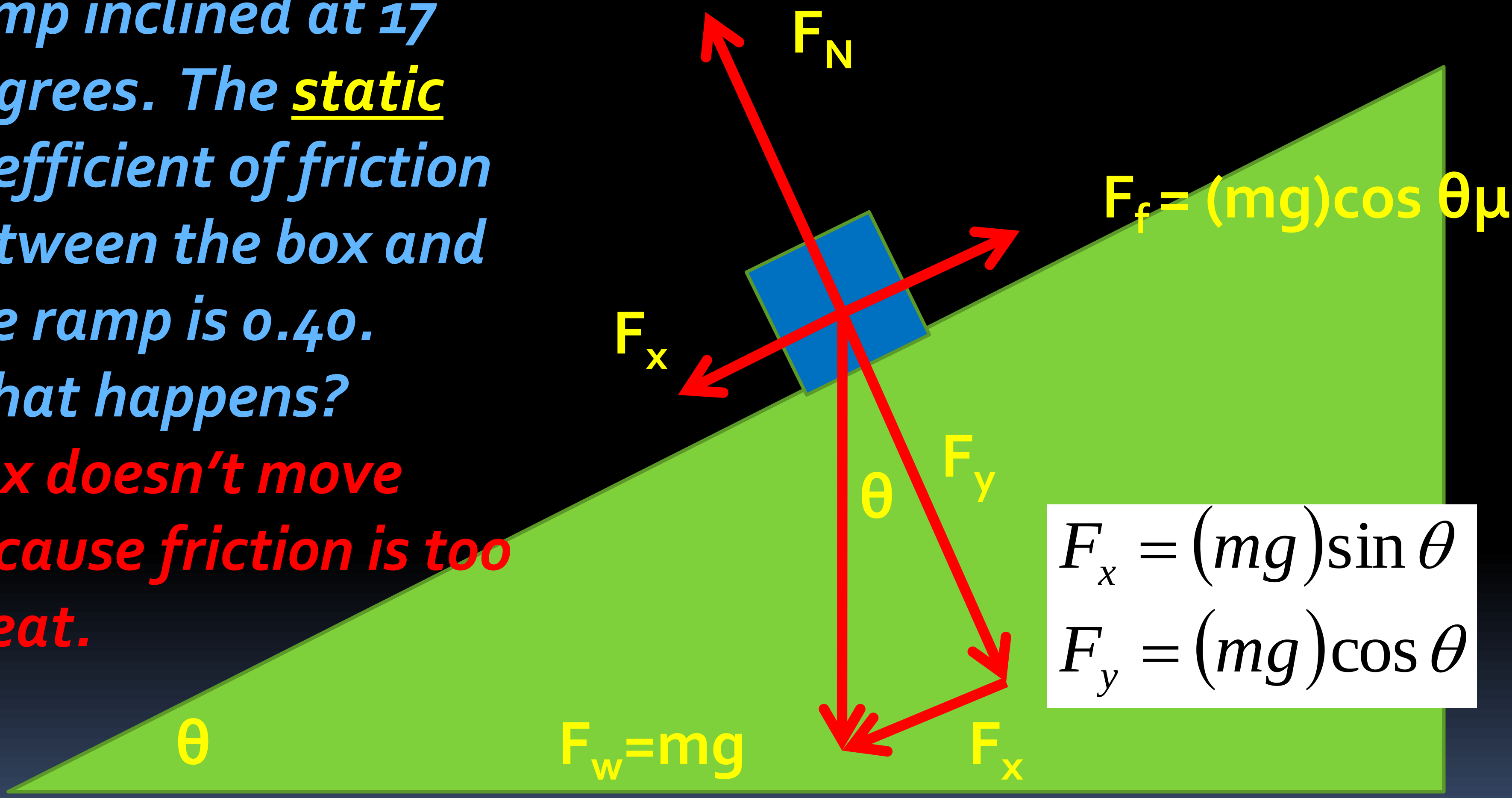
$$F_x = (mg)\sin\theta$$

$$F_y = (mg)\cos\theta$$

Inclined Plane

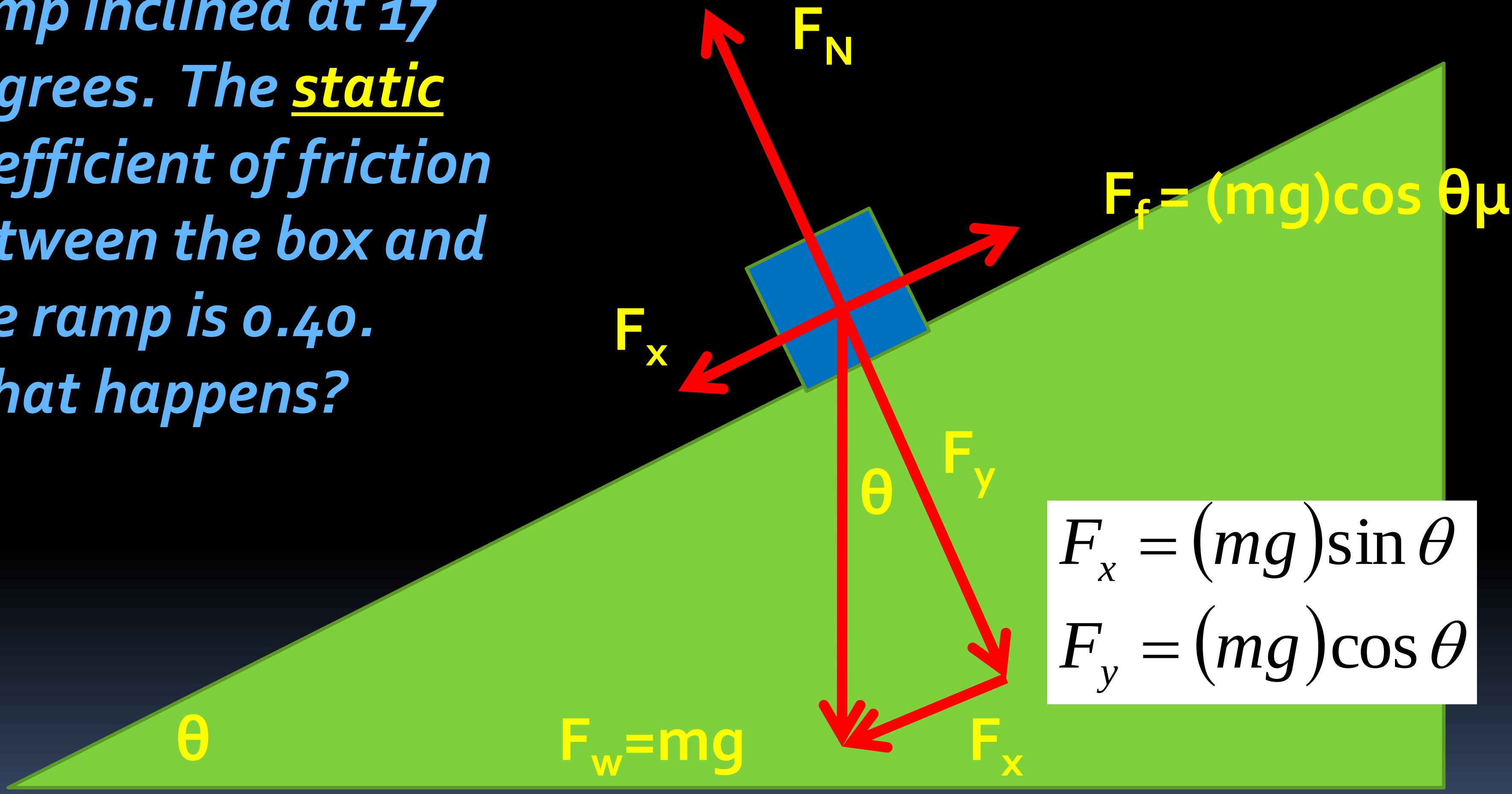
*A 10kg box sits on a ramp inclined at 17 degrees. The **static** coefficient of friction between the box and the ramp is 0.40. What happens?*

Box doesn't move because friction is too great.



Inclined Plane

*A **1000kg** box sits on a ramp inclined at 17 degrees. The **static** coefficient of friction between the box and the ramp is 0.40. What happens?*



$$F_x = (mg)\sin\theta$$

$$F_y = (mg)\cos\theta$$

$$F_x = (mg)\sin\theta$$

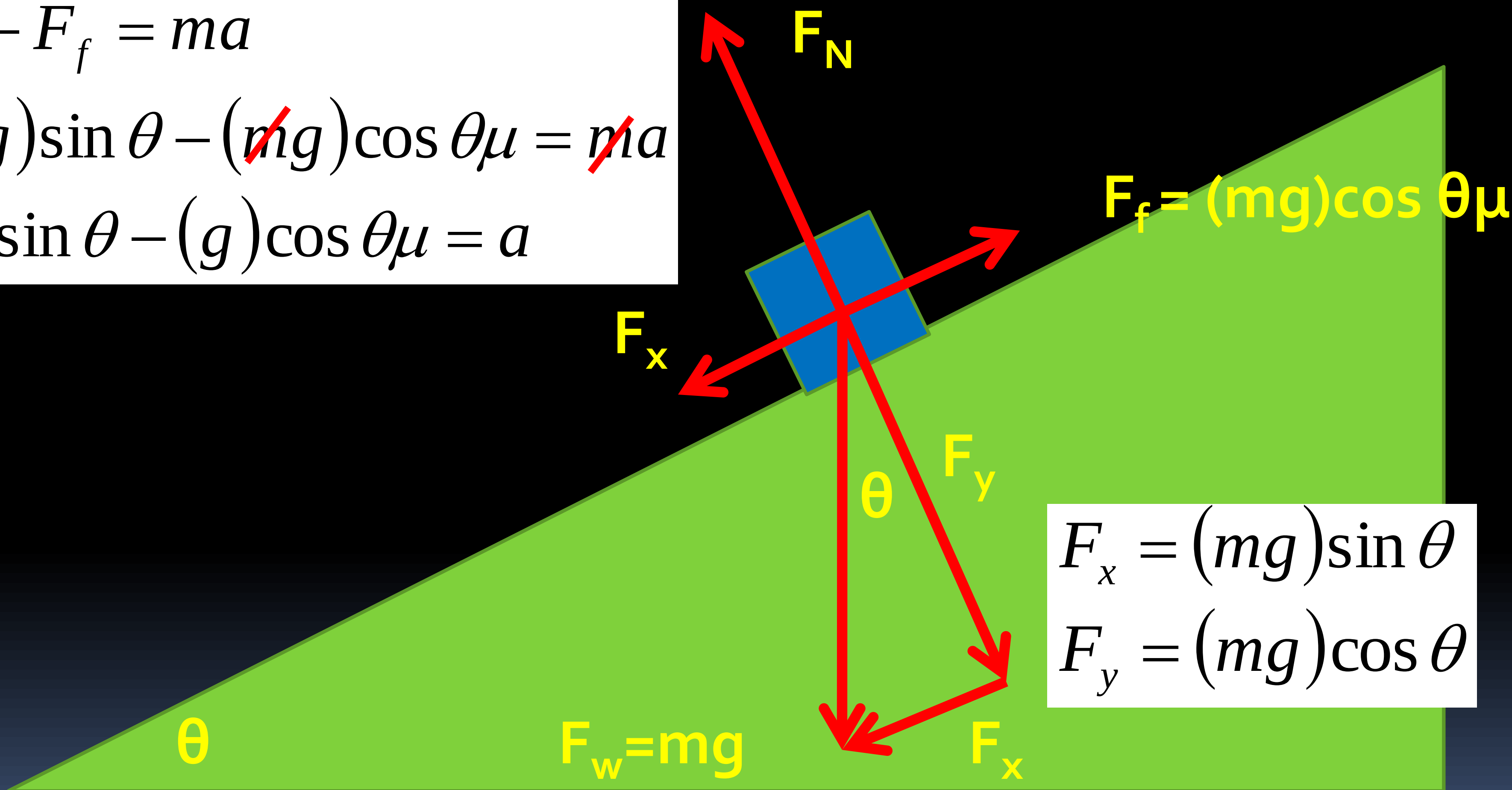
$$\Sigma F = ma$$

$$F_x - F_f = ma$$

$$(\cancel{m}g)\sin\theta - (\cancel{m}g)\cos\theta\mu = \cancel{m}a$$

$$(g)\sin\theta - (g)\cos\theta\mu = a$$

Inclined Plane



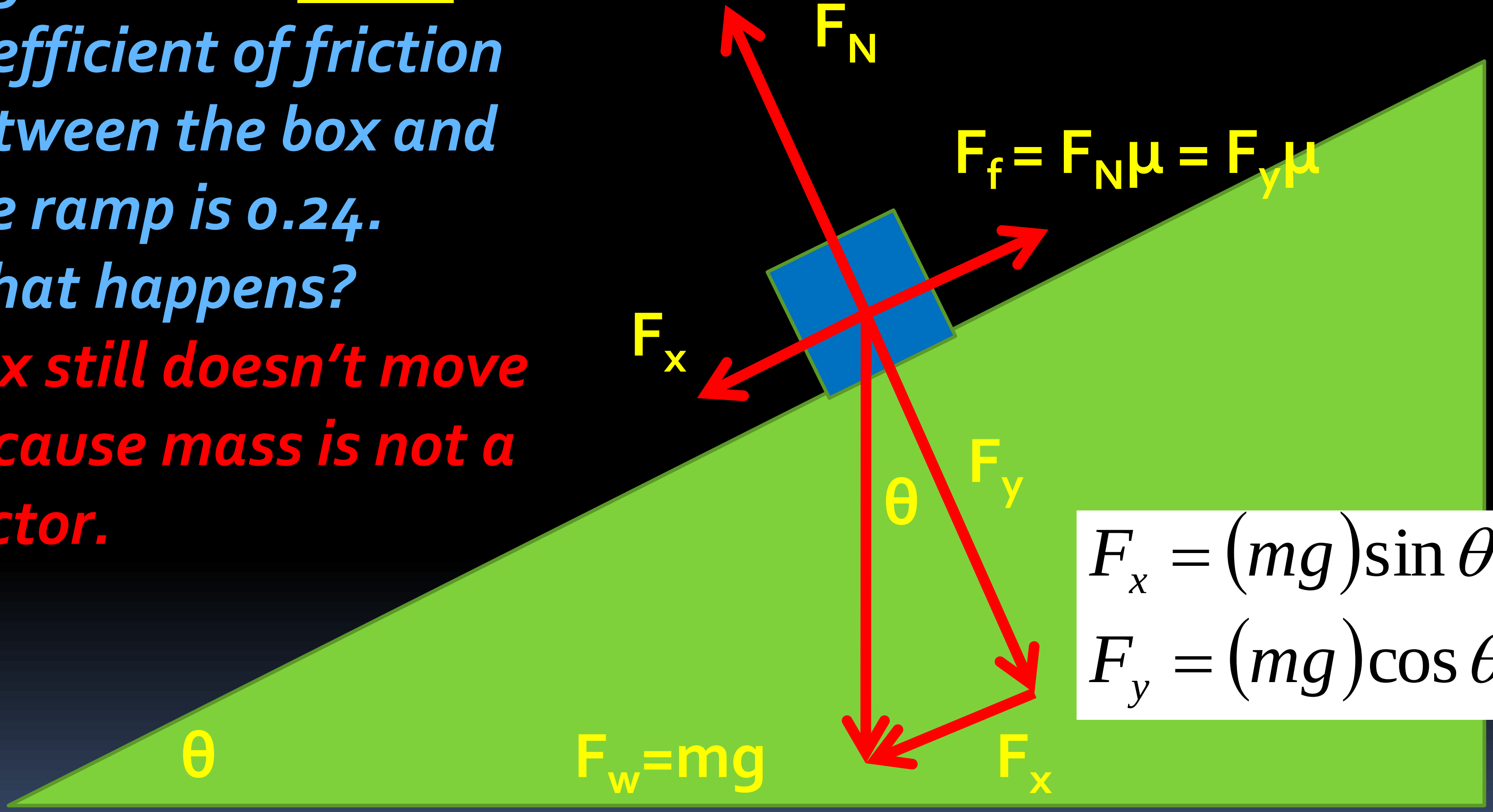
$$F_x = (mg)\sin\theta$$

$$F_y = (mg)\cos\theta$$

Inclined Plane

*A **1000kg** box sits on a ramp inclined at 17 degrees. The **static** coefficient of friction between the box and the ramp is 0.24. What happens?*

Box still doesn't move because mass is not a factor.

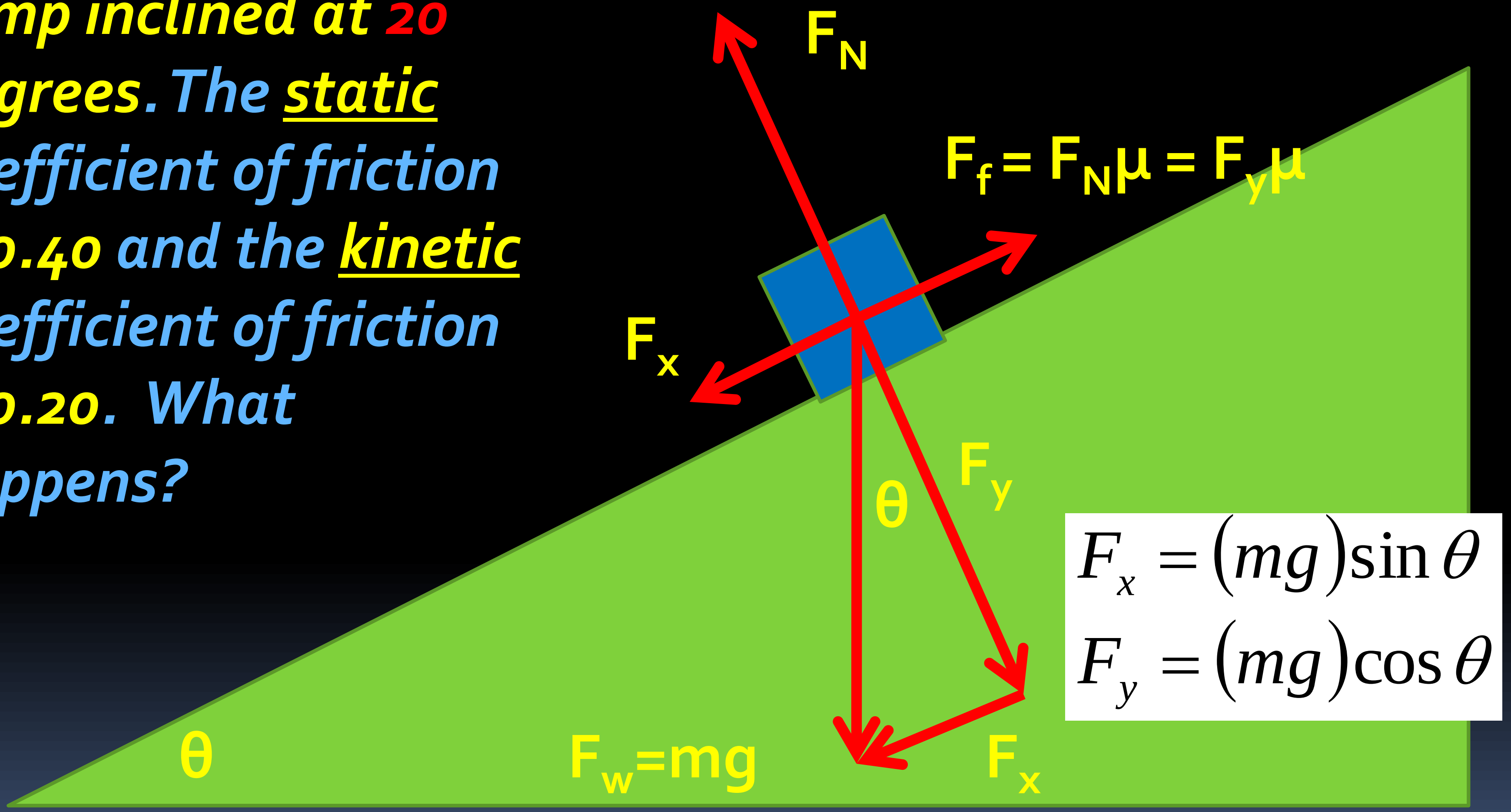


$$F_x = (mg)\sin\theta$$

$$F_y = (mg)\cos\theta$$

Inclined Plane

A 10kg box sits on a ramp inclined at 20 degrees. The <u>static</u> coefficient of friction is 0.40 and the <u>kinetic</u> coefficient of friction is 0.20. What happens?



Inclined Plane

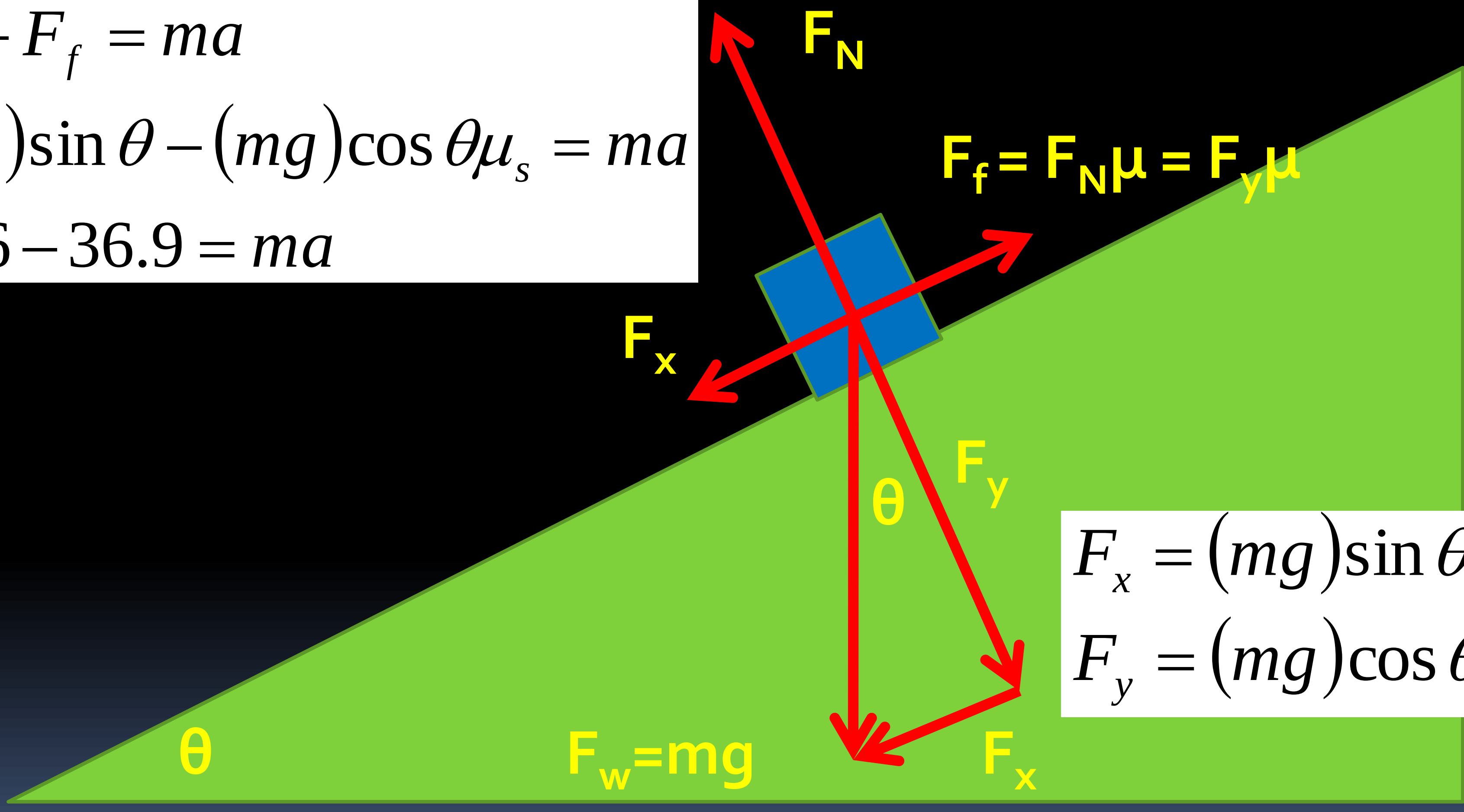
$$\mu_s = 0.40, \theta = 20°, m = 10kg$$

$$\Sigma F = ma$$

$$F_x - F_f = ma$$

$$(mg)\sin\theta - (mg)\cos\theta\mu_s = ma$$

$$33.6 - 36.9 = ma$$



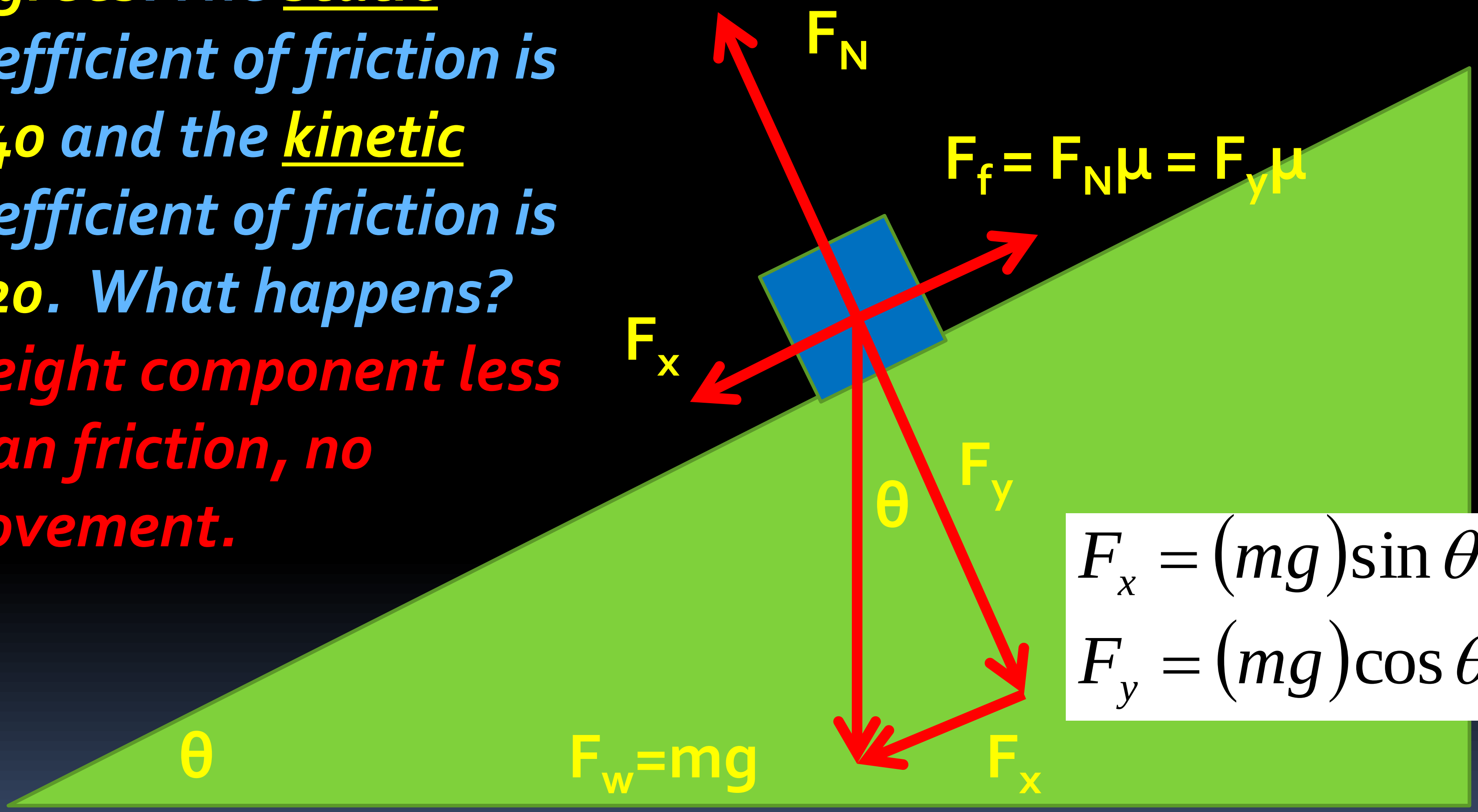
$$F_x = (mg)\sin\theta$$

$$F_y = (mg)\cos\theta$$

*A 10kg box sits on a ramp inclined at 20 degrees. The **static** coefficient of friction is 0.40 and the **kinetic** coefficient of friction is 0.20. What happens?*

Weight component less than friction, no movement.

Inclined Plane



$$F_x = (mg)\sin\theta$$

$$F_y = (mg)\cos\theta$$

Inclined Plane

$$\mu_k = 0.20, \theta = 20°, m = 10kg$$

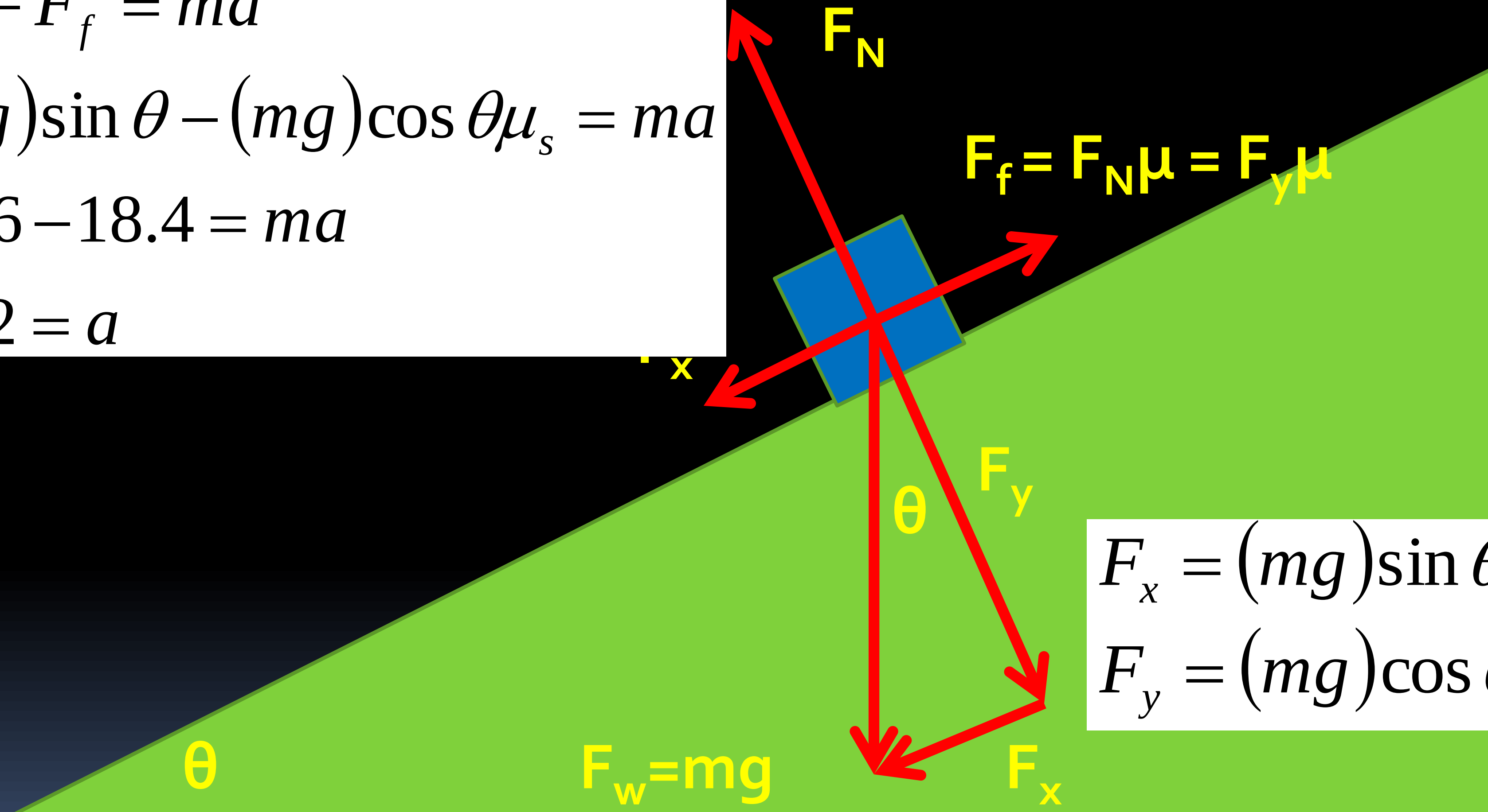
$$\Sigma F = ma$$

$$F_x - F_f = ma$$

$$(mg)\sin\theta - (mg)\cos\theta\mu_s = ma$$

$$33.6 - 18.4 = ma$$

$$1.52 = a$$



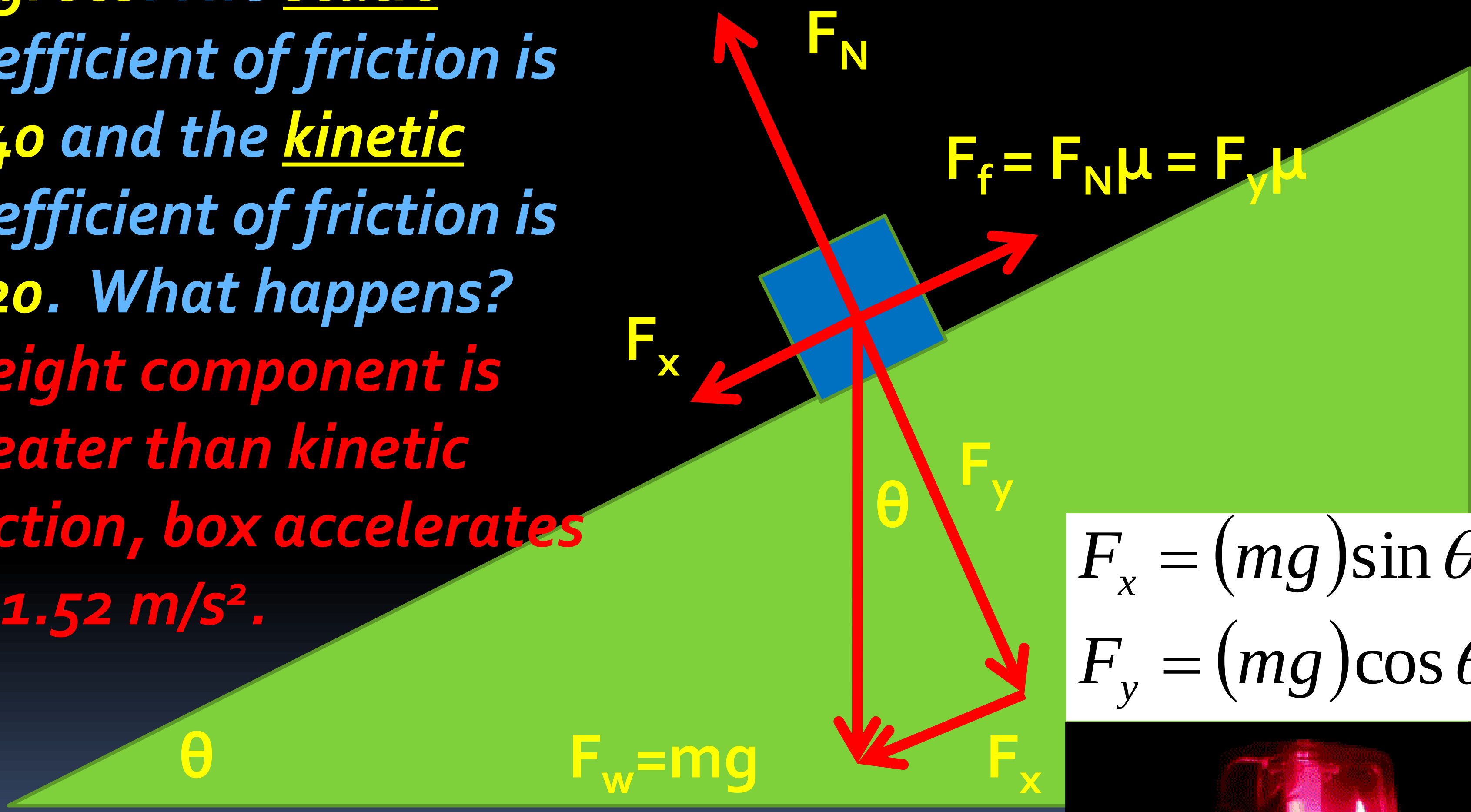
$$F_x = (mg)\sin\theta$$

$$F_y = (mg)\cos\theta$$

Inclined Plane

A 10kg box sits on a ramp inclined at 20 degrees. The __static__ coefficient of friction is 0.40 and the __kinetic__ coefficient of friction is 0.20. What happens?

Weight component is greater than kinetic friction, box accelerates at 1.52 m/s².



$$F_x = (mg)\sin\theta$$
$$F_y = (mg)\cos\theta$$

Box will slide if "nudged".

Problem-Solving Process – Pg 96

1. Read the problem carefully.
2. Draw a picture of the problem. Draw separate free-body diagrams for each object in the system.
3. Choose a coordinate system. Resolve forces into components. Apply F = ma for each component.

Problem-Solving Process – Pg 96

4. List knowns and unknowns – knowns include what can be inferred from the situation. Ensure compatible units. Define equations relating all variables.
5. Estimate your answer.
6. Solve the equations – algebra is your friend.
7. Make sure the units cancel out and answer is in correct units.
8. Check reasonableness of final answer.

Learning Objective(s):

- (1.C.1.1): The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
- (2.B.1.1): The student is able to apply to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems.
- (3.A.1.1): The student is able to express the motion of an object using narrative, mathematical, and graphical representations.

Learning Objective(s):

- (3.A.1.2): The student is able to design an experimental investigation of the motion of an object.
- (3.A.1.3): The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations.
- (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.

Learning Objective(s):

- (3.A.3.1): The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces.
- (3.A.4.1): The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces.
- (3.A.4.2): The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact.

Learning Objective(s):

- (3.B.1.1): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension.
- (3.B.1.2): The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.

Learning Objective(s):

- (3.B.1.4): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations.
- (3.C.4.1): The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces.

Learning Objective(s):

- (3.C.4.2): The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions.
- (3.G.1.1): The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.

Learning Objective(s):

- (4.A.3.1): The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system.

Essential Knowledge(s):

- 1.C.1: Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems.

Essential Knowledge(s):

- 2.B.1: A gravitational field at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.
  - On the Earth, this gravitational force is called weight.
  - The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
  - If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in newtons/kilogram) at that location.

Essential Knowledge(s):

- 3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
  - Displacement, velocity, and acceleration are all vector quantities.
  - Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.
  - A choice of reference frame determines the direction and the magnitude of each of these quantities.

Essential Knowledge(s):

- 3.A.3: A force exerted on an object is always due to the interaction of that object with another object.
  - An object cannot exert a force on itself.
  - Even though an object is at rest, there may be forces exerted on that object by other objects.
  - The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

Essential Knowledge(s):

- 3.A.2: Forces are described by vectors.
  - Forces are detected by their influence on the motion of an object.
  - Forces have magnitude and direction.
- 3.A.4: If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

Essential Knowledge(s):

- 3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- 3.C.4: Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).

Essential Knowledge(s):

- 3.G.1: Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.
- 4.A.3: Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

Enduring Understanding(s):

- 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- 2.B: A gravitational field is caused by an object with mass.
- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.

Enduring Understanding(s):

- 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $a = \frac{F}{m}$
- 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

Enduring Understanding(s):

- 3.G: Certain types of forces are considered fundamental.
- 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where

$$\vec{a} = \frac{\vec{F}}{m}$$

Big Idea(s):

- Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
- Big Idea 2: Fields existing in space can be used to explain interactions.

Big Idea(s):

- Big Idea 3: The interactions of an object with other objects can be described by forces.
- Big Idea 4: Interactions between systems can result in changes in those systems.

QUESTIONS

Homework

#36-57