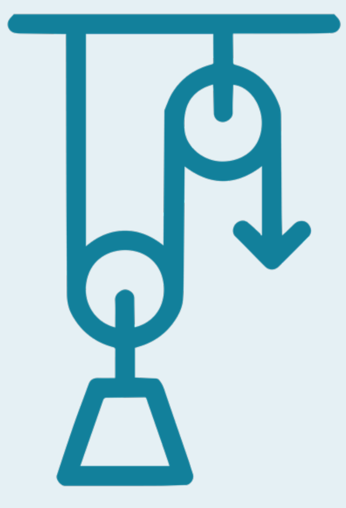
elevate

YEAR 11 PHYSICS

MODULE 2

LESSON THREE



THEORY

Inclined Planes and Friction

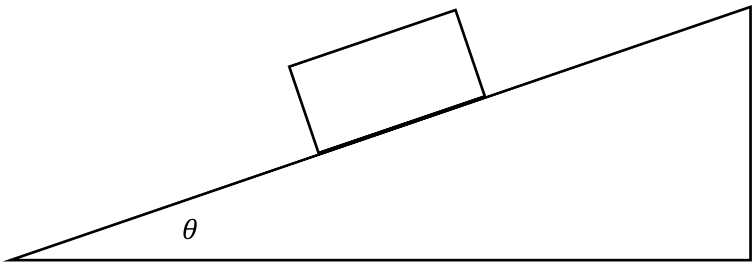
2.1.4 Conduct a practical investigation to explain and predict the motion of objects on inclined planes

Whilst we have only explored movement of objects on **level planes** thus far, we must understand that not all motion occurs on perfectly horizontal surfaces.

In fact, they may occur on **inclined planes** instead, in which case we must pay close attention to how the force of gravity can affect the motion of an object.

On the diagram below, label the following forces:

- Weight force
- Normal force



Draw a free-body diagram by first resolving the weight force vector into components that are

- Parallel to the ramp and
- Perpendicular to the ramp

THEORY

EXAMPLE QUESTION

If an object is released from rest at the top of the ramp, explain with reference to a vector in the free-body diagram above, why we can confidently say that it speeds up.

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EXAMPLE QUESTION

If the box is motionless on the ramp and a scale was placed underneath it, determine whether the reading would be higher or lower than if the scale were on flat ground.

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EXAMPLE QUESTION

A 15kg box is placed on a frictionless ramp which makes an angle of 30° with the horizontal.

a. Draw an appropriate free-body diagram, having resolved all relevant vectors.

THEORY

b. Compare the magnitudes of the normal and weight forces and explain the reason for the difference.

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c. Determine the acceleration of the box down the ramp.

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d. Determine the speed of the box once it reaches the bottom of the ramp, if the box moves 15m, along the ramp.

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EXAMPLE QUESTION

A 30kg toddler sits on a 5kg toboggan at the top of a slope angled at 10° to the horizontal and slides down the slope.

a. Determine his speed at the bottom of the slope if he started at rest and the slope is 30m long.

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b. Explain how the toddler's speed at the bottom of the slope varies with the angle of inclination of the slope.

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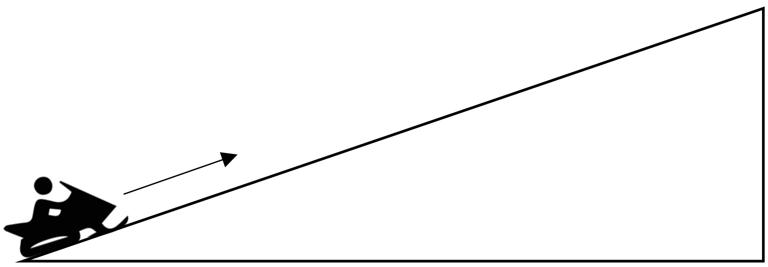
EXAMPLE QUESTION

A 100kg snowmobile carrying an 80kg rider attempts to travel up a frictionless snow-slope inclined at 20° to the horizontal.



a. Draw an appropriate free-body diagram, having resolved all relevant vectors.

b. If the rider approaches the bottom of the slope at a speed of 30km/h, calculate the force that the engine must be producing for the snowmobile to maintain this speed during its time on the slope.

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THEORY

c. Determine the thrust required from the engine if the snowmobile wanted to double its speed by the time it reached the top of the slope which is 45m *above* the ground level where the rider started.

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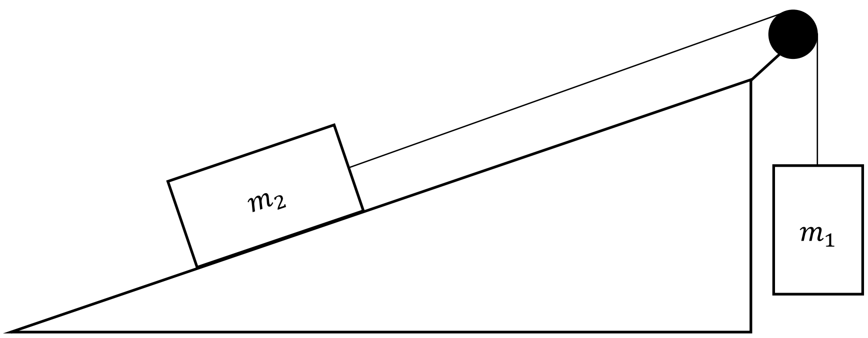
Similarly, we may also encounter pulleys and Atwood machines (or Semi-Atwood machines to be more accurate) on inclined planes.

EXAMPLE QUESTION

See the following questions pertaining to the system below. $\boldsymbol{m_1 > m_2}$



a. Draw an appropriate free-body diagram, having resolved all relevant vectors.

THEORY

b. Derive an expression for the acceleration of the entire system.

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c. Derive an expression for the tension in the string.

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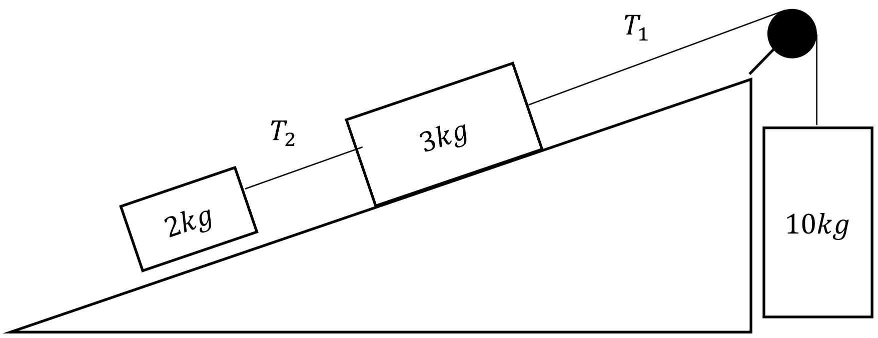
EXAMPLE QUESTION

See the following questions pertaining to the system below.



a. Draw an appropriate free-body diagram, having resolved all relevant vectors.

THEORY

b. Determine the magnitude of the acceleration of the entire system.

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c. With the aid of an appropriate free-body diagram, determine the magnitude of the tensile force T_1

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THEORY

d. With the aid of an appropriate free-body diagram, determine the magnitude of the tensile force T_2

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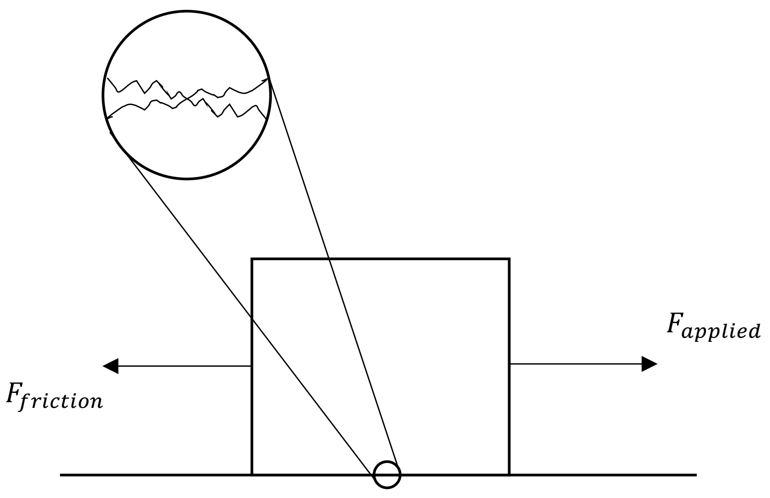
2.2.1 Apply Newton's first two laws of motion to a variety of everyday situations, including both static and dynamic examples, and include the role played by friction $f_{friction} = \mu F_N$

Recall our discussion of friction in Lesson 1 as a force which acts parallel to the movement of an object and impedes motion.



THEORY

Friction arises due to the **interlocking** that occurs between irregular bumps on the two surfaces in contact.

Importantly, there are two types of friction:

- Static friction
- Kinetic friction

The frictional force is a fraction of the **Normal force** and is given by:

$$F_{fr} = \mu N$$

Where:

- μ is the coefficient of friction
- N is the normal force (N)

The **coefficient of friction (μ)** is a unitless fraction which indicates the relative ease with which two surfaces will slide over each other:

$$0 \leq \mu \leq 1$$

If two surfaces are more abrasive and likely to incur a greater frictional force, then the value of μ will be higher i.e. the frictional force is a greater fraction of the normal force

STATIC FRICTION (μ_s)

Whenever an object is placed atop another surface, considerable interlocking between irregularities will occur straight away.

If you were to try to push the object, you would experience some resistance up until a point where it gives way, and the object starts moving.

The frictional force experienced up until the object moves is known as **static friction**.

Static friction is given by:

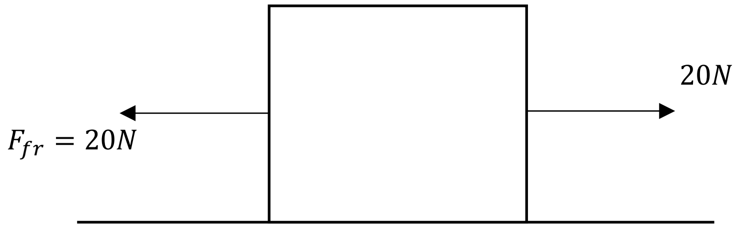
$$F_{fr} = \mu_s N$$

It is important to understand that static friction is a **threshold force**.

THEORY

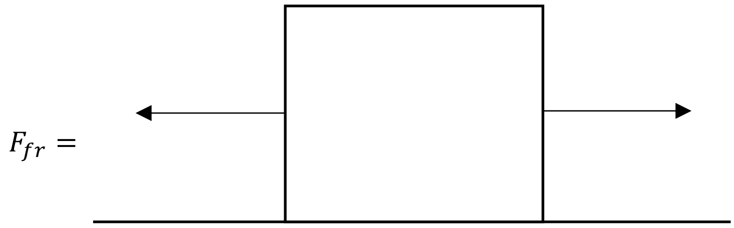
Say for example a box can experience 40N of static friction. If the applied force were only 10N, it would only experience 10N of frictional force in resistance.

Say now, the applied force was 20N, it would only experience 20N of frictional force in resistance.



EXAMPLE QUESTION

Label the diagram below if 30N of force were applied on the same box from above.



It is only when the full 40N of force is applied, that the surface exerts its 40N of friction back.

At forces any higher than this, the surface can no longer match the force and we say that it has reached its **threshold.**

At this point, the object starts moving, and static friction no longer applies.

THEORY

KINETIC FRICTION (μ_k)

Once the object begins to move, there is still a frictional force, albeit much less than when it was stationary.

The frictional force experienced while the object is in motion is known as **kinetic friction.**

The coefficients of kinetic friction are lesser than that of static friction. See the table of examples below.

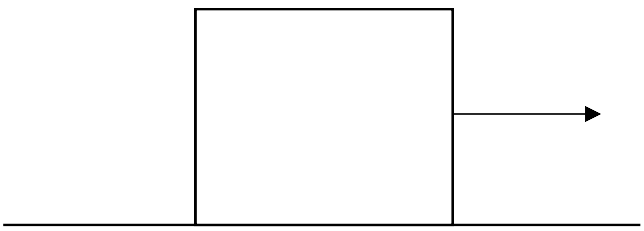
Kinetic friction is given by:

$$F_{fr} = \mu_k N$$

Surfaces	Static friction (μ_s)	Kinetic friction (μ_k)
Plastic, concrete	0.9	0.7
Plastic, wet concrete	0.7	0.4
Plastic, ice	0.15	0.09

EXAMPLE QUESTION

A $3kg$ box rests on a surface with a coefficient of static friction (μ_s) of 0.60.



a. Determine the force with which it needs to be pushed horizontally, for it to *start* moving.

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THEORY

b. Given that the coefficient of kinetic friction (μ_k) is 0.30 and that the student applies the same force as in part a. calculate the net force on the box once it is in motion.

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c. Determine the speed of the box after 10 seconds in motion.

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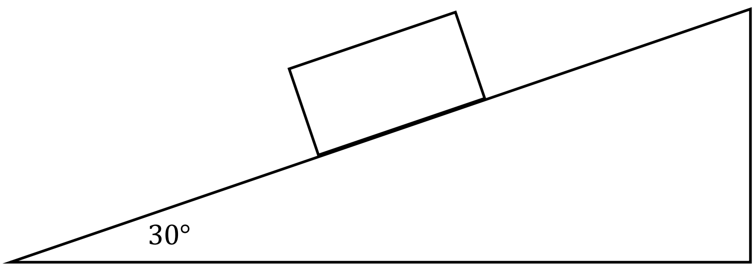
The notion of friction can also be applied to the more complex examples of dynamics we have learnt.

See the example questions below:

EXAMPLE QUESTION

A 5kg box is placed on a slope where μ_s=0.50, $\mu_k = 0.23$.



THEORY

a. Draw an appropriate free-body diagram, having resolved all relevant vectors.

b. What is the condition which must be satisfied for the box to start moving?

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c. Given that the box is initially at rest, determine whether the box begins to move. If so, determine its velocity after 5 seconds in motion.

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THEORY

d. A student places the box on a ramp with a smaller angle of inclination. The box does not move. She makes the following statement:

> *"The component of gravitational force that is present parallel to the slope is insufficient to counteract the force of friction"*

By deriving a relevant expression, assess the accuracy of her statement.

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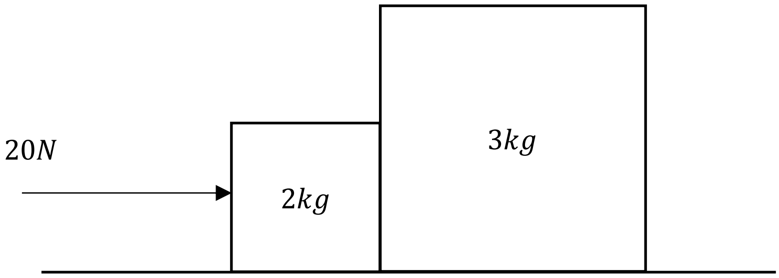
PRACTICE QUESTIONS

1. **Two boxes are moving under the influence of a force on a surface where $\mu_k = 0.23$**



a. Draw an appropriate free-body diagram representing the entire system

(1 mark)

b. Calculate the acceleration of the entire system

(2 mark)

c. Hence, calculate the net-force on each box

(2 mark)

PRACTICE QUESTIONS

d. Draw a free-body diagram of the forces acting on the $2kg$ mass

(1 mark)

e. Hence, determine the force that the $3kg$ mass exerts on the $2kg$ mass

(1 mark)

f. Draw a free-body diagram of the forces acting on the $3kg$ mass

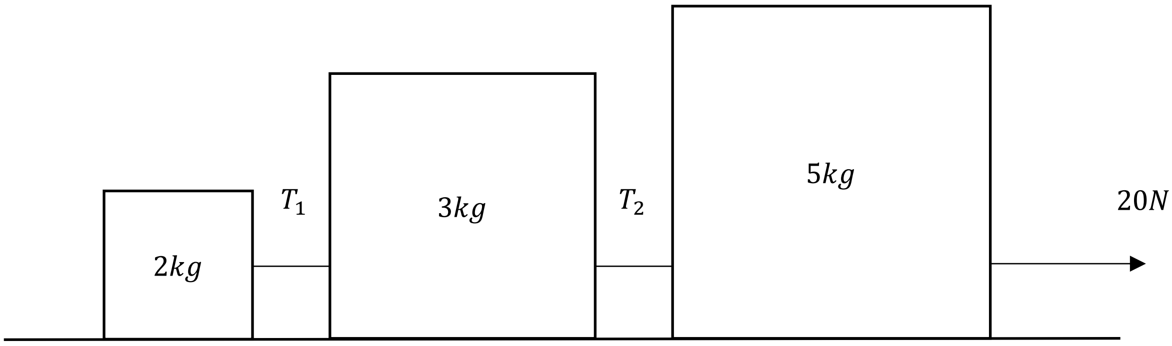
(1 mark)

g. Hence, determine the force that the $2kg$ mass exerts on the $3kg$ mass

(1 mark)

PRACTICE QUESTIONS

2. **Each mass is attached to the next by a taut rope and are pulled with a force of 50N to the right.** $\mu_k = 0.18$.



a. Draw an appropriate free-body diagram representing the entire system

(1 mark)

b. Calculate the acceleration of the entire system

(2 marks)

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c. Hence, calculate the net-force on each box

(1 mark)

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PRACTICE QUESTIONS

d. Calculate the values of T_1 and T_2

(2 marks)

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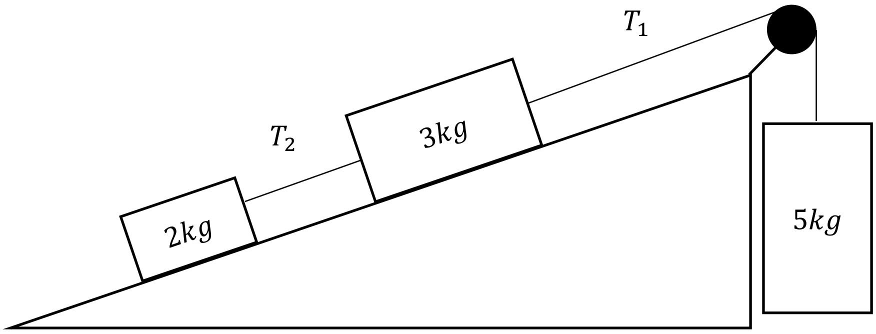
HOMEWORK

1. **Compare and contrast static and kinetic friction, with reference to examples.**

   (3 marks)

2. **The slope in the diagram below is inclined at an angle of 30° to the horizontal and μ_s=0.50, $\mu_k = 0.16$**



   a. Draw an appropriate free-body diagram representing the entire system and resolve all relevant vectors.

   (1 mark)

HOMEWORK

b. Determine whether the system is motion and if so, determine the acceleration of the entire system.

(3 marks)

c. With the aid of an appropriate free-body diagram, determine the magnitude of the tensile force T_1

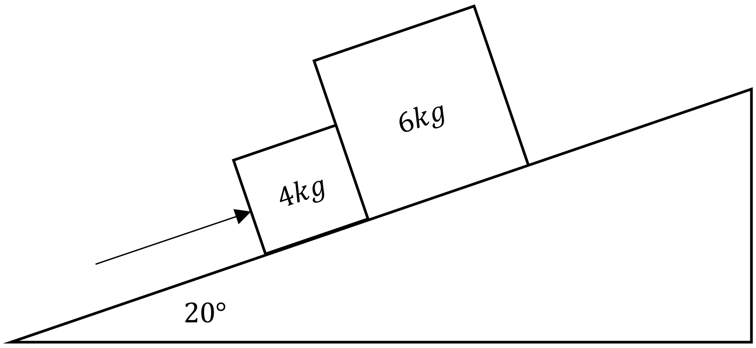
(3 marks)

d. With the aid of an appropriate free-body diagram, determine the magnitude of the tensile force T_2

(3 marks)

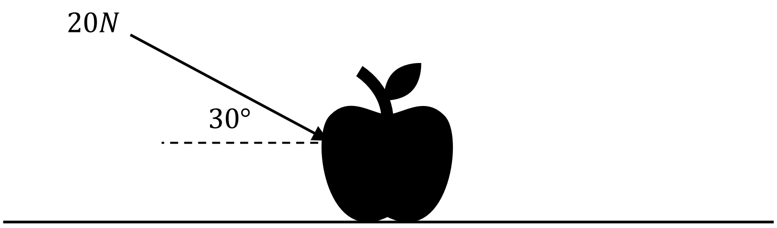
3. **Compare the force required to get the two boxes on the slope below (μ_s=0.48) moving, as compared to if it was a frictionless surface.**

(4 marks)



HOMEWORK

4. Xavier pushes a 100g apple across the table as shown by the diagram below.



a. Determine the coefficient of static friction if the apple only started to move once Xavier applied the full 20N of force in the manner shown above.

(3 marks)

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b. If the coefficient of kinetic friction is a third of the value of that pertaining to static friction, determine the velocity of the apple after 2.5 seconds of motion if Xavier keeps pushing with the same force.

(3 marks)

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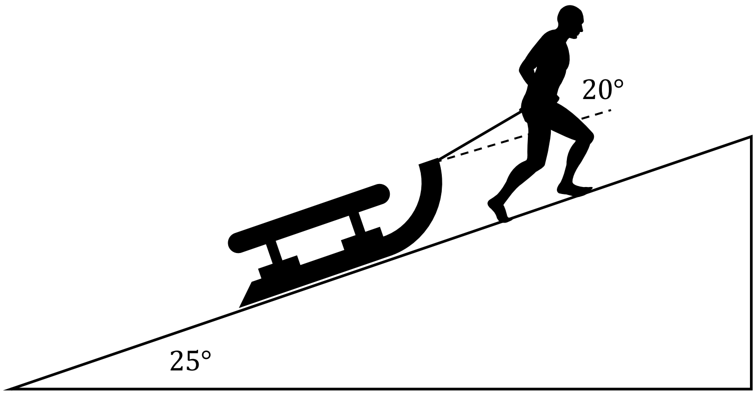
HOMEWORK

5. A man pulls a 20kg toboggan up a hill where (μ_k=0.15).



a. Draw an appropriate free-body diagram representing the forces on the toboggan.

(1 mark)

b. Determine the force with which the man must pull the toboggan if the toboggan moves up the slope at a constant velocity.

(4 marks)

HOMEWORK

c. Propose ONE method by which the man can pull the sled to the top, at the same constant velocity, albeit exerting less effort. Explain your answer.

(2 marks)

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elevate