Ramp Problems

Unit: Dynamics (Forces) & Gravitation

NGSS Standards: N/A

MA Curriculum Frameworks (2006): N/A

AP Physics 1 Learning Objectives: 1.C.1.1, 2.B.1.1, 3.A.2.1, 3.B.1.1, 3.B.1.2, 3.B.1.3, 3.B.2.1, 4.A.2.3, 4.A.3.1, 4.A.3.2

Skills:

- calculate the forces on a ramp

Language Objectives:

- Set up and solve word problems involving forces on a ramp.

Labs, Activities & Demonstrations:

- Objects sliding down a ramp at different angles.
- Set up ramp with cart & pulley and measure forces at different angles.

Notes:

The direction of the normal force does not always directly oppose gravity. For example, if a block is resting on a (frictionless) ramp, the weight of the block is $\vec{F}_g$, in the direction of gravity. However, the normal force is perpendicular to the ramp, not to gravity.

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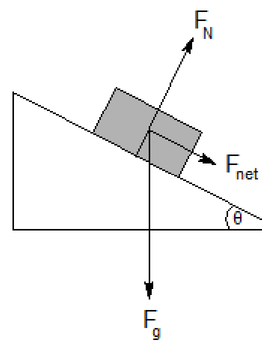
If we were to add the vectors representing the two forces, we would see that the resultant—the net force—acts down the ramp:



Intuitively, we know that if the ramp is horizontal $(\theta = 0)$, the net force is zero and $\vec{F}_N = \vec{F}_g$, because they are equal and opposite.

We also know intuitively that if the ramp is vertical $(\theta = 90°)$, the net force is $\vec{F}_g$ and $\vec{F}_N = 0$.

If the angle is between 0 and 90°, the net force must be between 0 and $\vec{F}_g$, and the proportion must be related to the angle (trigonometry!). Note that $\sin(0°) = 0$ and $\sin(90°) = 1$. Intuitively, it makes sense that multiplying $\vec{F}_g$ by the sine of the angle should give the net force down the ramp for any angle between 0 and 90°.

Similarly, If the angle is between 0 and 90°, the normal force must be between $\vec{F}_g$ (at 0) and 0 (at 90°). Again, the proportion must be related to the angle (trigonometry!). Note that $\cos(0°) = 1$ and $\cos(90°) = 0$. Intuitively, it makes sense that multiplying $\vec{F}_g$ by the cosine of the angle should give the normal force for any angle 0 and 90°.

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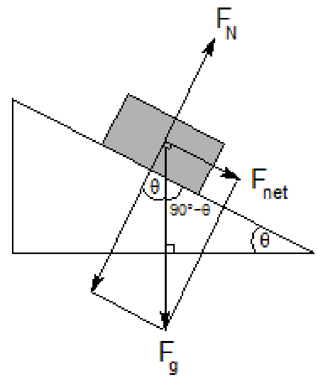
Let's look at a geometric explanation:

From geometry, we can determine that the angle of the ramp, θ, is the same as the angle between gravity and the normal force.

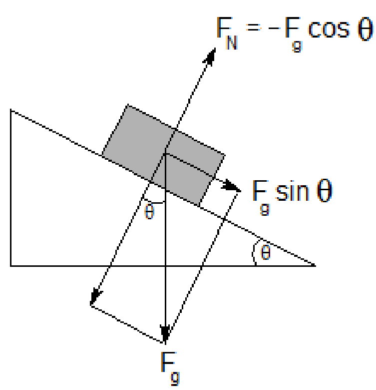


From trigonometry, we can calculate that the component of gravity parallel to the ramp (which equals the net force down the ramp) is the side *opposite* angle θ. This means:

$$F_{net} = F_g \sin\theta$$

The component of gravity perpendicular to the ramp is $F_g \cos\theta$, which means the normal force is:

$$F_N = -F_g \cos\theta$$



(The negative sign is because we have chosen down to be the positive direction.)

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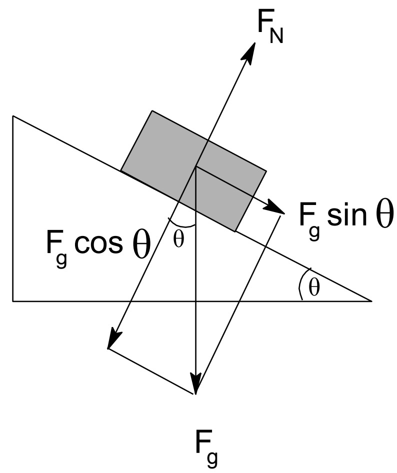
Sample Problem:

Q: A block with a mass of 2.5 kg sits on a frictionless ramp with an angle of inclination of 35°. How fast does the block accelerate down the ramp?

A: The weight of the block is $F_g = ma = (2.5)(10) = 25\,\text{N}$. However, the component of the force of gravity in the direction that the block slides down the ramp is $F_g \sin\theta$:



$$F_g \sin\theta = 25\sin 35° = (25)(0.574) = 14.3\,\text{N}$$

Now that we know the net force (in the direction of motion), we can apply Newton's Second Law:

$$F = ma$$
$$14.3 = 2.5\,a$$
$$a = 5.7\,\tfrac{\text{m}}{\text{s}^2}$$

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Homework Problem

1. A 10. kg block sits on a frictionless ramp with an angle of inclination of 30°. What is the rate of acceleration of the block?

Answer: $5.0\,\frac{\text{m}}{\text{s}^2}$

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