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General Physics: Mechanics

PHYS-101(en)

Lecture 3b: Problem solving, Newton's laws of motion

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Today's agenda

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1. General physics problem solving
2. Worked examples

Problem solving in physics

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A. Understand the problem
B. Plan your approach
C. Execute your approach
D. Review your solution

Problem solving in physics

A. Understand the problem
B. Plan your approach
} prepare

C. Execute your approach

D. Review your solution
} check

A. Understanding the problem

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1. Identify what you **want**
2. Identify what you **have**
3. Make it as clear as possible
   - Highlight quantities and symbols in the question
   - **Represent the situation by drawing pictures, graphs, etc.**
   - Use symbols, rather than numbers

B. Planning your approach

- What concepts are relevant?
- What models or physical principles are involved? Do they relate what you have and what you want?
- What information summarizes the situation?
- **Have you encountered similar problems before?**
- What reference frame/coordinate system is best?
- Are there details that can be ignored?
- If you're really in trouble, can you solve a simplified version of the problem?

C. Executing your approach

1. Keep notation simple
2. Examine your equations
   - Do you have enough equations to solve for all of your unknowns?
3. Solve symbolically (wait to substitute numbers until the end)
4. For long calculations, check that intermediate results make sense (e.g. units)

D. Reviewing your solution

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1. Does the solution make sense?
    1. Check units
        - Units must always agree
    2. Check the values themselves
        - If you calculated that a building is 3000 km tall, there may be an error
    3. Check special cases
        - What if the two objects have the same mass? What if one is infinitely heavier than the other?

Example: Towing a sled

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A mother tows her daughter on a sled along level ice. The friction between the sled and the ice is negligible, and the tow rope makes an angle of θ to the horizontal. The combined mass of the sled and the child is M. The sled has an acceleration in the horizontal direction of magnitude a. Calculate the tension, T, in the rope and the magnitude of the normal force, N, exerted by the ice on the sled.

Example [A. Understand the problem]

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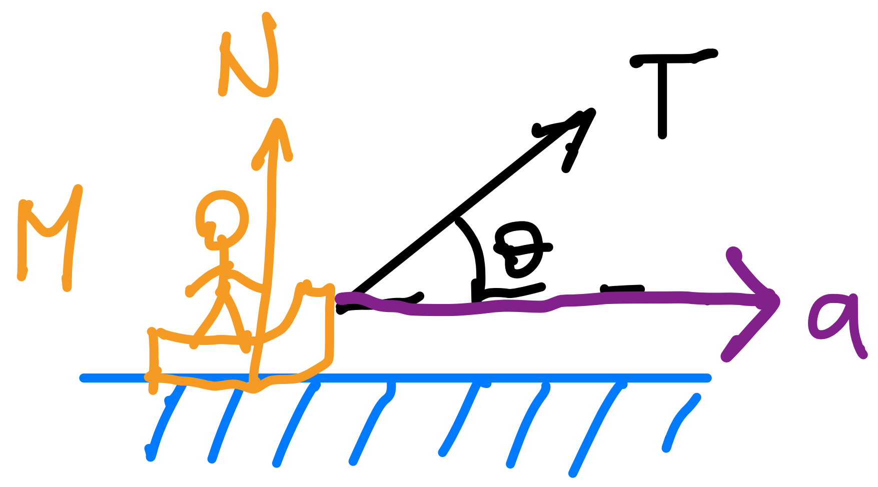
A mother tows her daughter on a sled along level ice. The friction between the sled and the ice is negligible, and the tow rope makes an angle of θ to the horizontal. The combined mass of the sled and the child is M. The sled has an acceleration in the horizontal direction of magnitude a. Calculate the tension, T, in the rope and the magnitude of the normal force, N, exerted by the ice on the sled.



Example [B. Plan approach]

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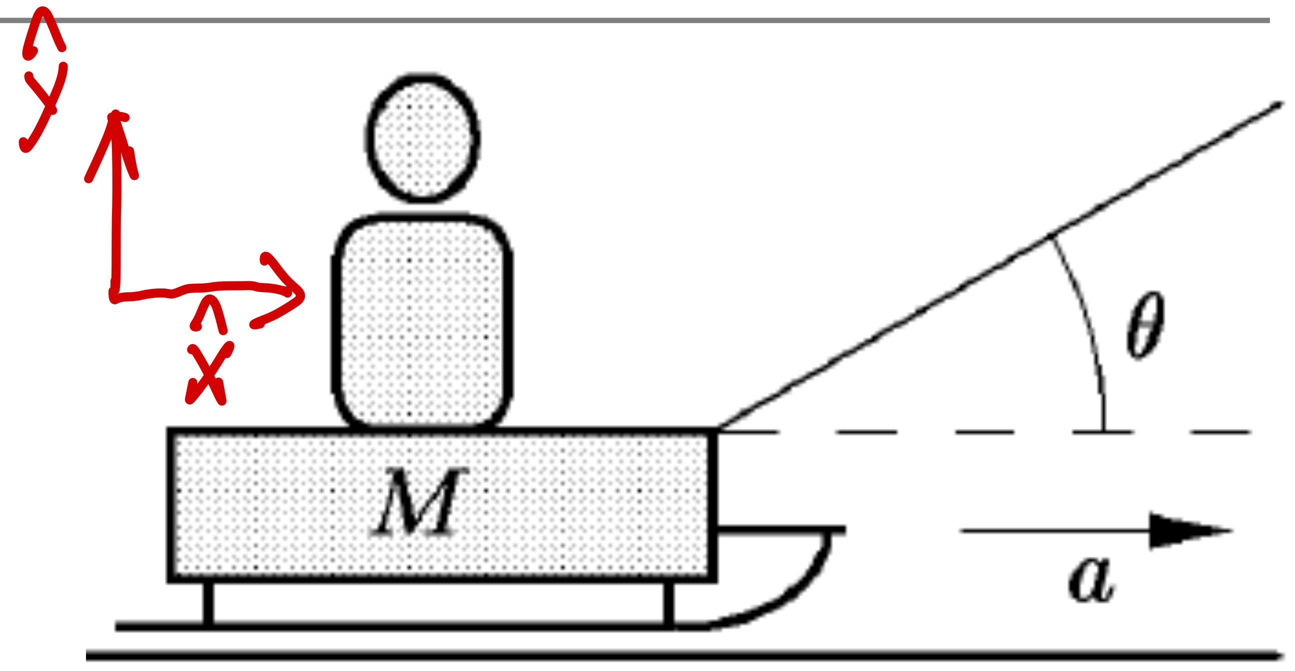
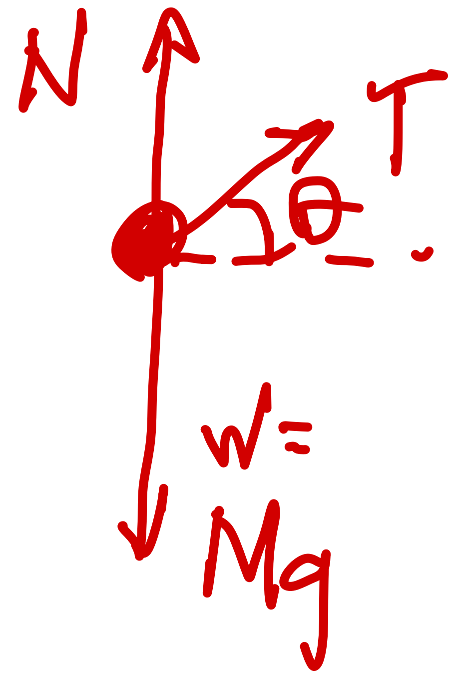
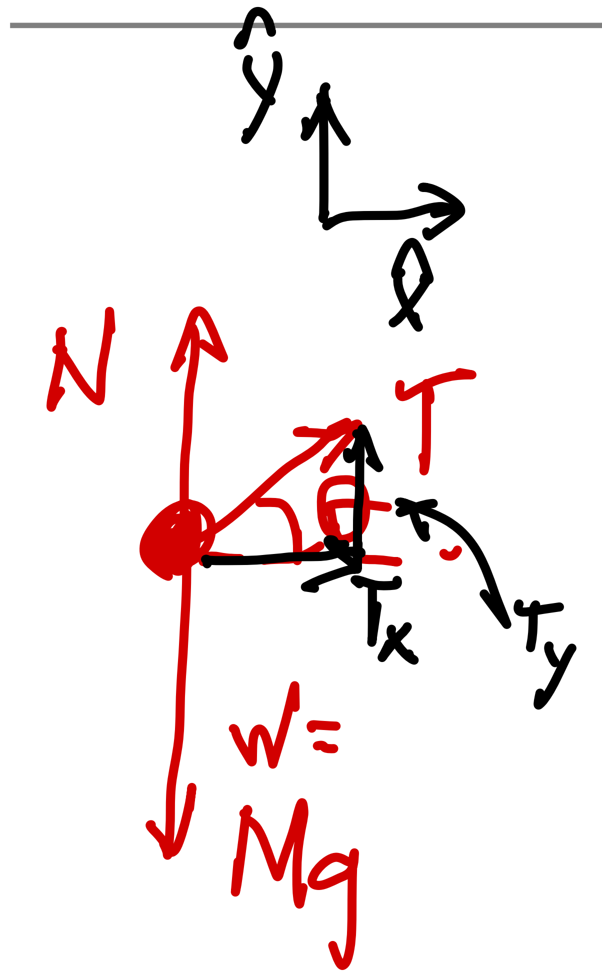
A mother tows her daughter on a sled along level ice. The friction between the sled and the ice is negligible, and the tow rope makes an angle of θ to the horizontal. The combined mass of the sled and the child is M. The sled has an acceleration in the horizontal direction of magnitude a. Calculate the tension, T, in the rope and the magnitude of the normal force, N, exerted by the ice on the sled.

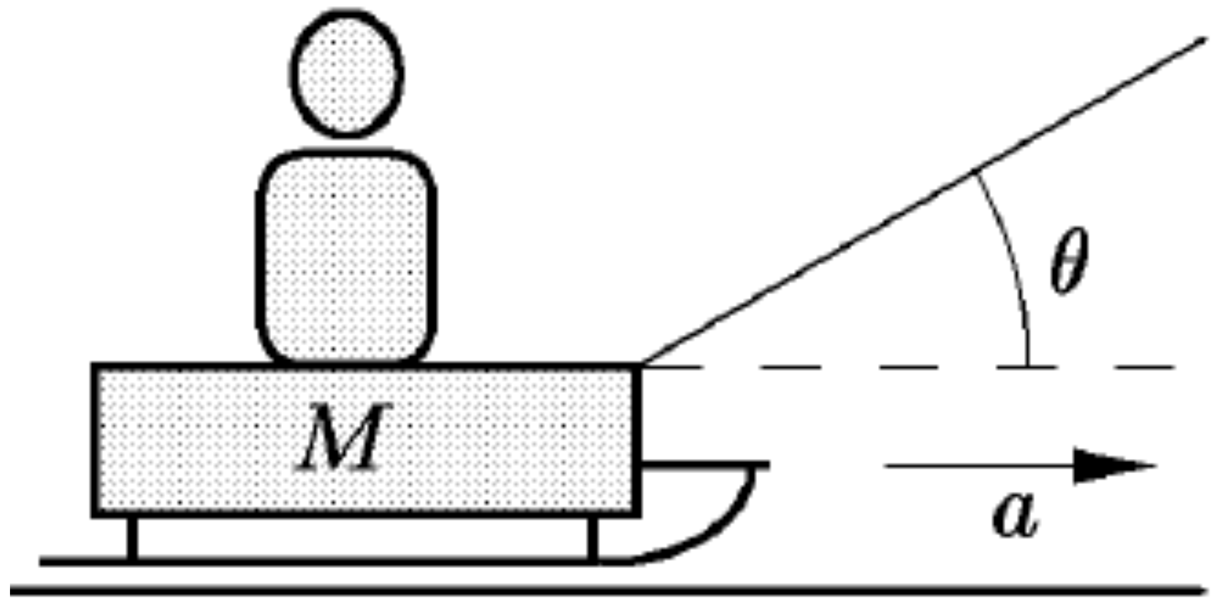


Force is a vector
Newton's 2nd law
No friction



Example [C. Execute approach]





$$\vec{T} = T_x \hat{x} + T_y \hat{y}$$

$$\cos(\theta) = \frac{T_x}{T} \Rightarrow T_x = T\cos(\theta) \qquad T_y = T\sin(\theta)$$

$$\sum \vec{F} = M\vec{a} = Ma\hat{x}$$

$$\text{In } \hat{x}: \quad T_x = Ma \Rightarrow T\cos(\theta) = Ma \Rightarrow \boxed{T = \frac{M}{\cos(\theta)} a}$$

$$\text{In } \hat{y}: \quad N + T_y - Mg = 0$$

$$\Rightarrow N = Mg - T_y = Mg - T\sin(\theta) = Mg - \left(\frac{M}{\cos(\theta)} a\right)\sin(\theta)$$

$$= Mg - M\tan(\theta)\, a$$

$$= \boxed{M(g - a\tan(\theta))} = N$$

Example [D. Review solution]

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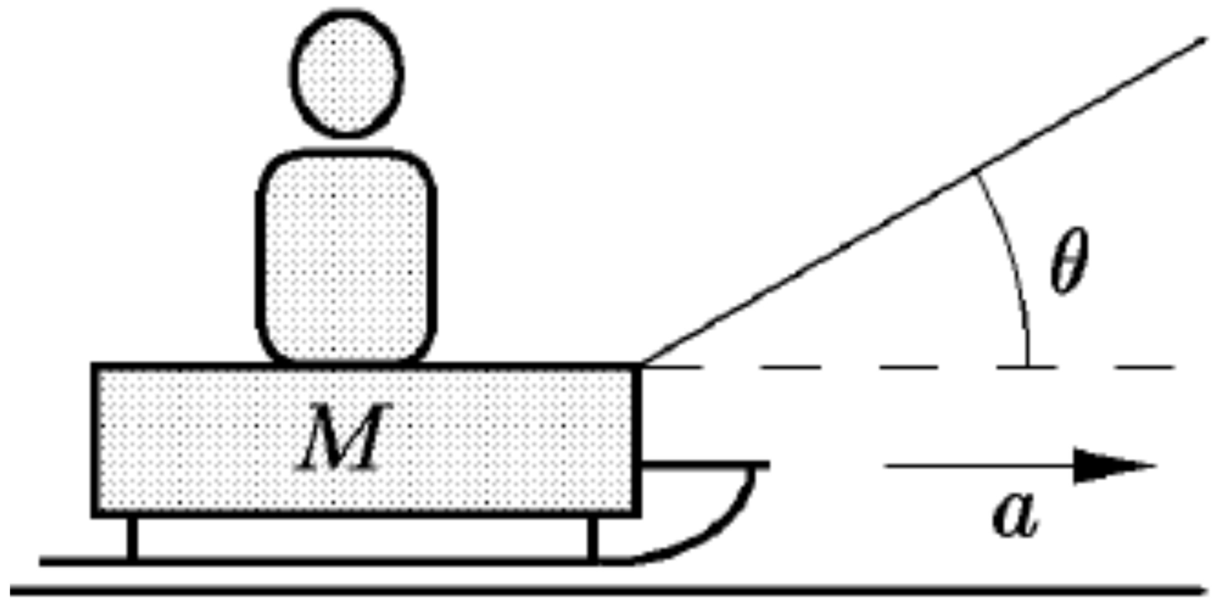
A mother tows her daughter on a sled along level ice. The friction between the sled and the ice is negligible, and the tow rope makes an angle of θ to the horizontal. The combined mass of the sled and the child is M. The sled has an acceleration in the horizontal direction of magnitude a. Calculate the tension, T, in the rope and the magnitude of the normal force, N, exerted by the ice on the sled.



$$T = \frac{M}{\cos(\theta)} a$$

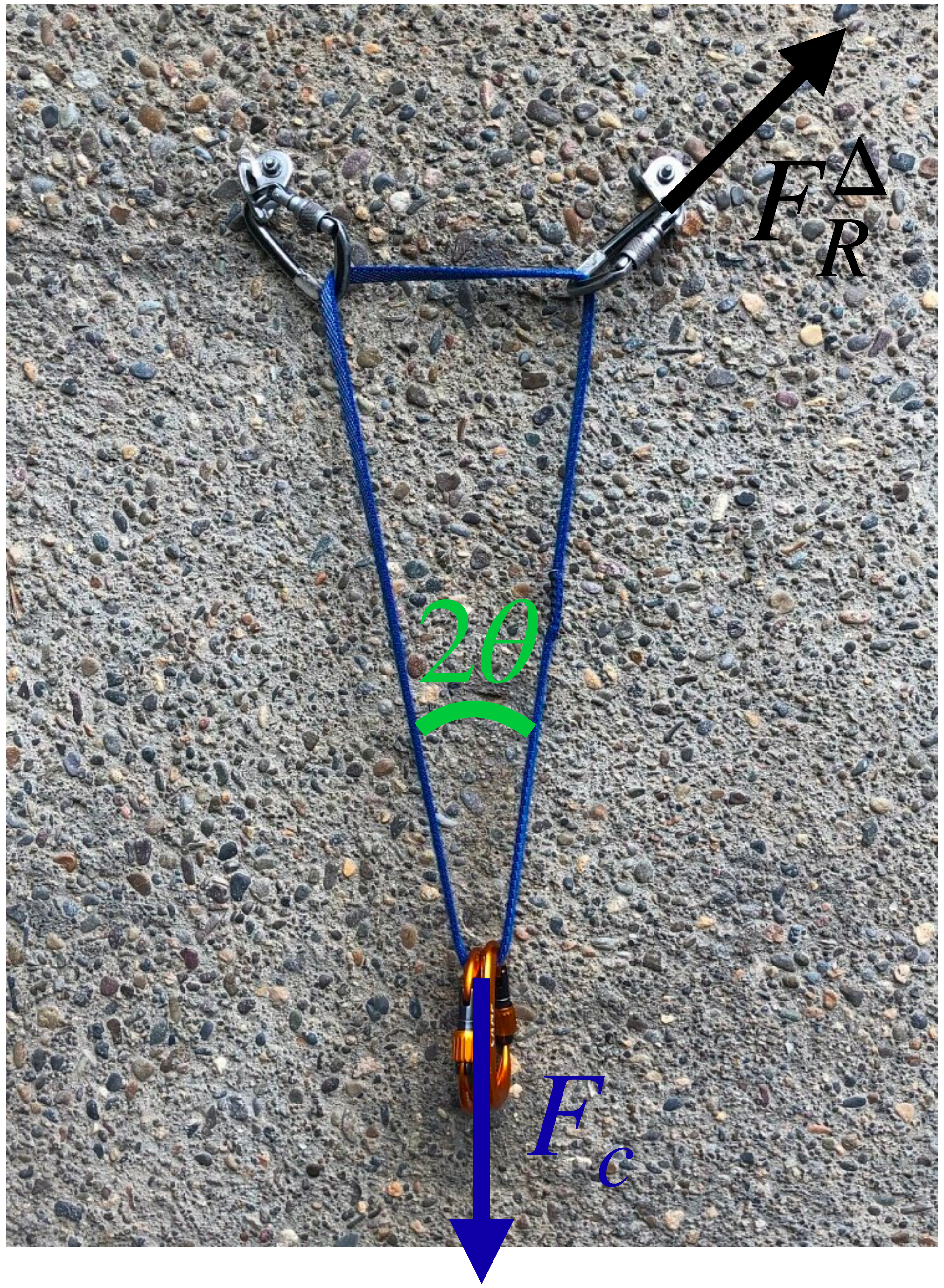
$$N = \boxed{M(g - a\tan(\theta))}$$

If $\theta = 0$, $\begin{cases} T = \frac{M}{1} a = Ma \\ N = M\cdot(g - a\cdot 0) = Mg \end{cases}$

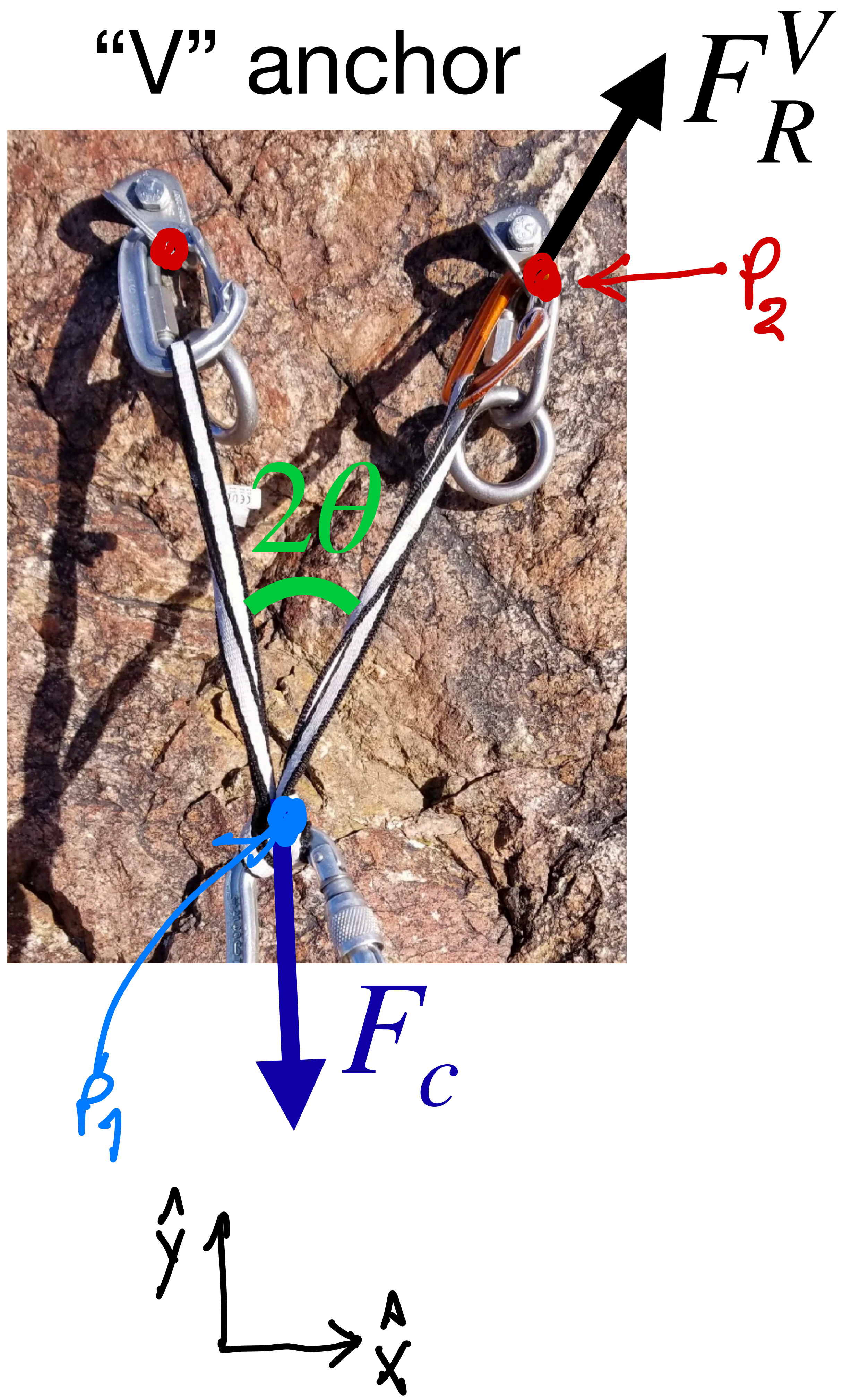
Example: Climbing anchors

"V" anchor

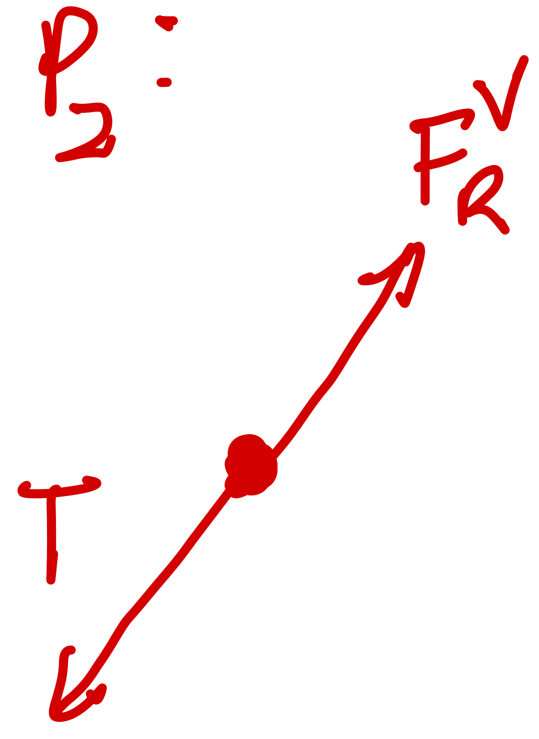
Triangle anchor



Example: "V" anchor

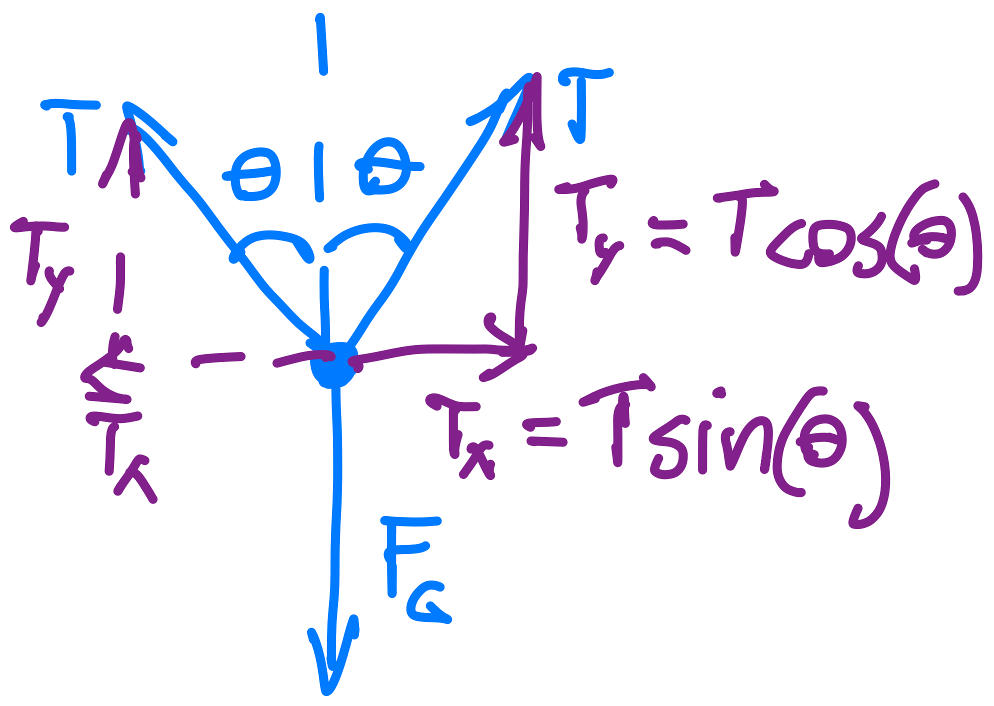


P_2:



$F_R^V = T$

P_1:



In $\hat{y}$:

$T_y + T_y - F_c = 0$

$\Rightarrow 2T_y = F_c$

$\Rightarrow T_y = \frac{1}{2} F_c$

$\Rightarrow T\cos(\theta) = \frac{1}{2} F_c$

$$F_R^V = T = \frac{1}{2\cos(\theta)} F_c$$

Example: Triangle anchor

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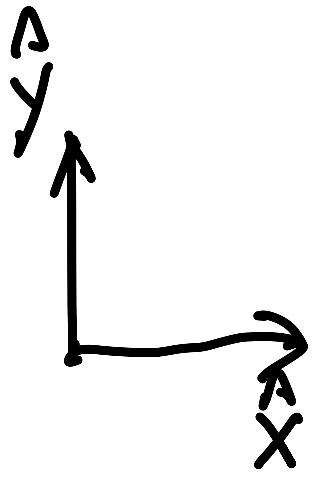
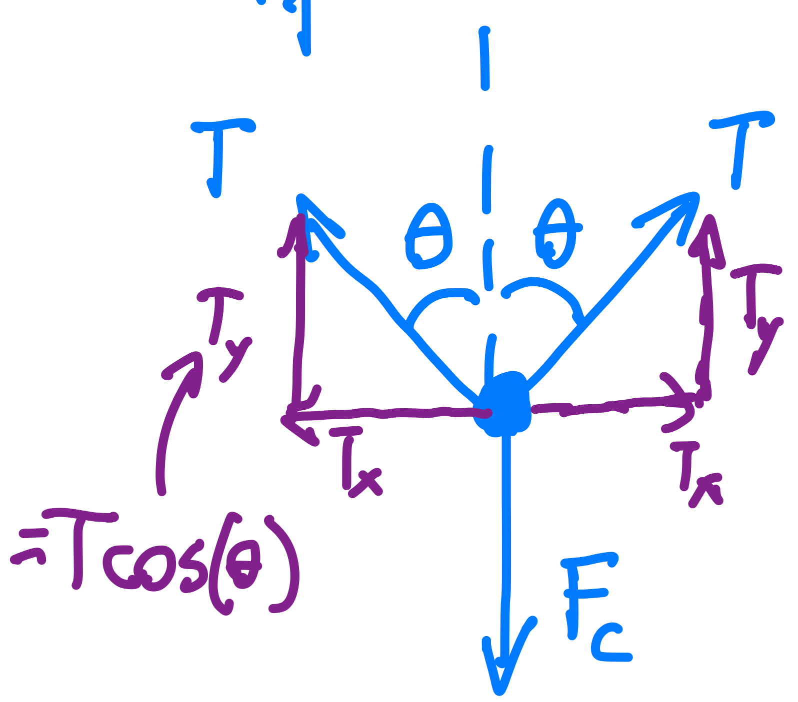
Triangle anchor

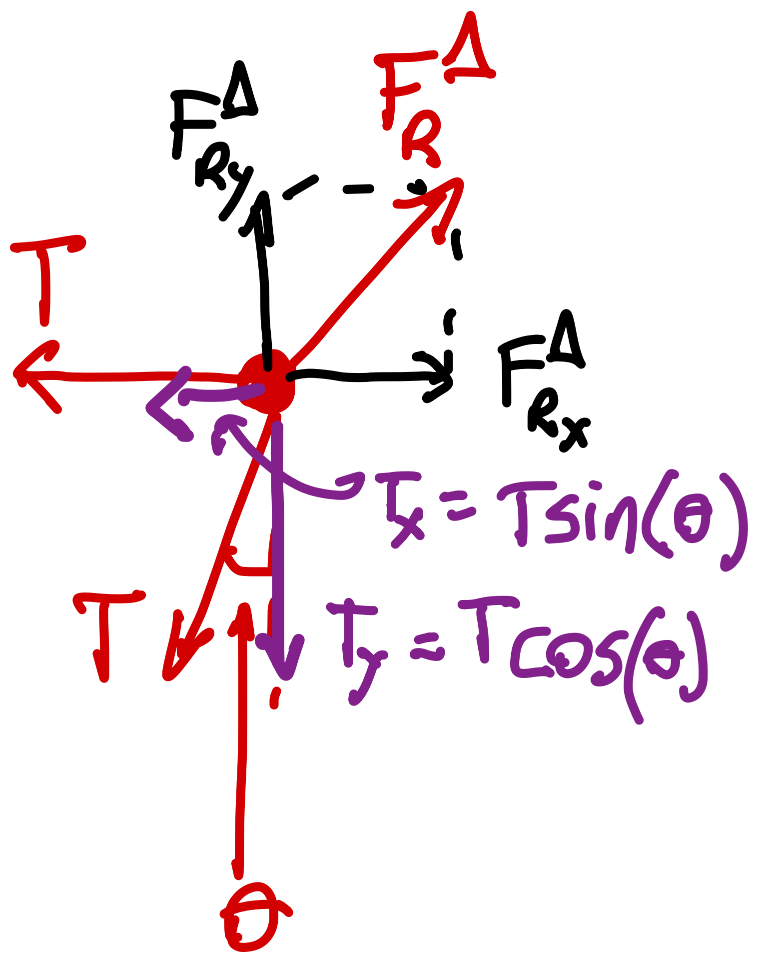


p_1:



$$T = \frac{T_y}{\cos(\theta)} = \frac{1}{2\cos(\theta)} F_c = F_R^V$$

p_2:



In $\hat{y}$:

$$F_{Ry}^\Delta - T_y = 0$$

$$\Rightarrow F_{Ry}^\Delta = T_y = T\cos(\theta)$$

In $\hat{x}$:

$$F_{Rx}^\Delta - T - T_x = 0$$

$$\Rightarrow F_{Rx}^\Delta = T + T_x = T + T\sin(\theta)$$

$$F_R^\Delta = \sqrt{(F_{Rx}^\Delta)^2 + (F_{Ry}^\Delta)^2} = \sqrt{T^2\cos^2(\theta) + [T + T\sin(\theta)]^2}$$

$$= T\sqrt{\cos^2(\theta) + 1 + 2\sin(\theta) + \sin^2(\theta)} = T\sqrt{2 + 2\sin(\theta)}$$

$$= T \cdot \sqrt{2}\sqrt{1 + \sin(\theta)} = F_R^V \cdot \sqrt{2}\sqrt{1 + \sin(\theta)}$$

Example: Which climbing anchor is better?

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"V" anchor

$$F_R^V = \frac{1}{2\cos(\theta)} F_C$$

$$F_R^\Delta = F_R^V \cdot \underbrace{\sqrt{2}\sqrt{1+\sin(\theta)}}_{>1}$$

$$> F_R^V$$

← Safer!

Triangle anchor