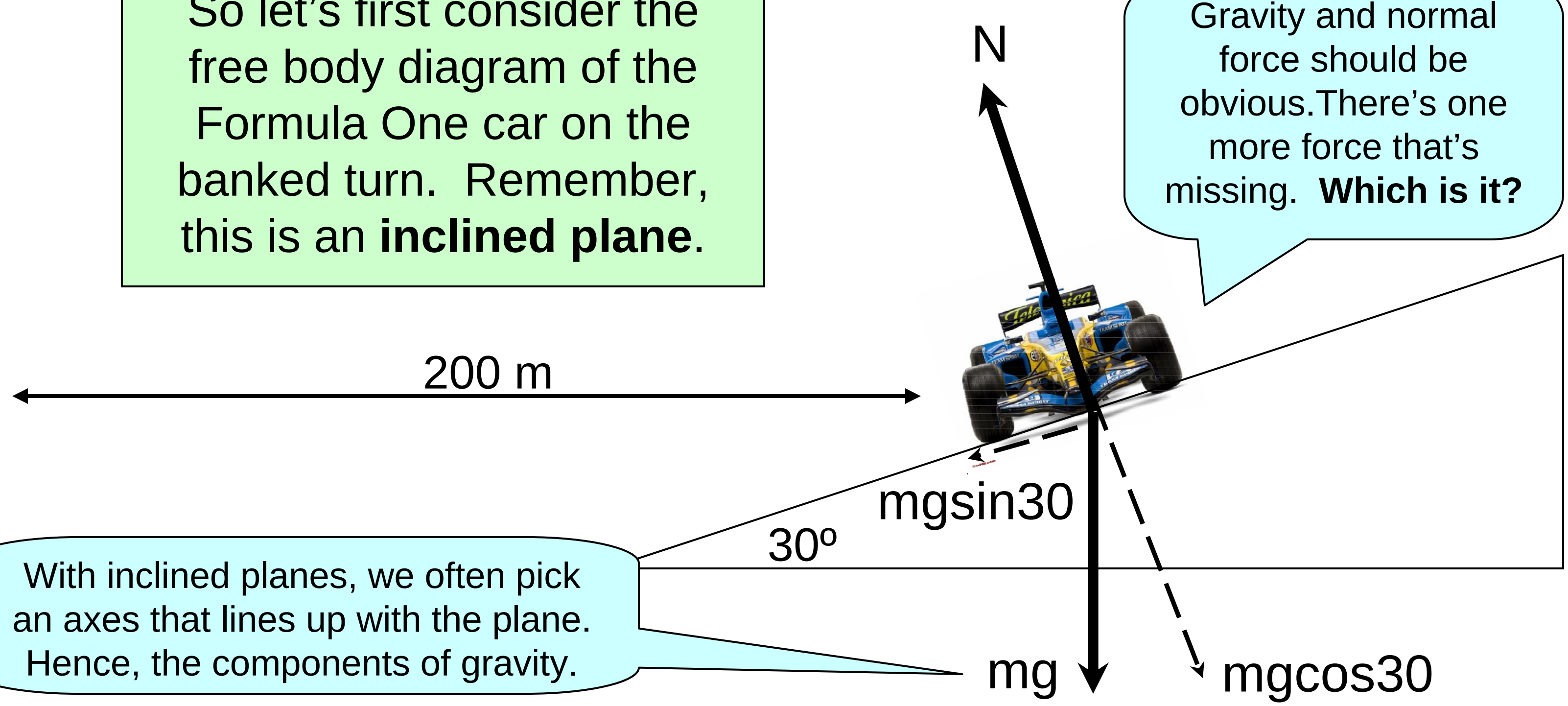
Physics – Newtonian Dynamics (Inclined Planes, Friction and Centripetal Force)

A Formula One racer is attempting to negotiate a 30 degrees banked turn of radius 200 m. The coefficient of static friction between the tires and the track is 0.50. Determine both the minimum and the maximum speed with which the car can safely negotiate the turn.

So let's first consider the free body diagram of the Formula One car on the banked turn. Remember, this is an **inclined plane**.

Gravity and normal force should be obvious.There's one more force that's missing. **Which is it?**



With inclined planes, we often pick an axes that lines up with the plane. Hence, the components of gravity.

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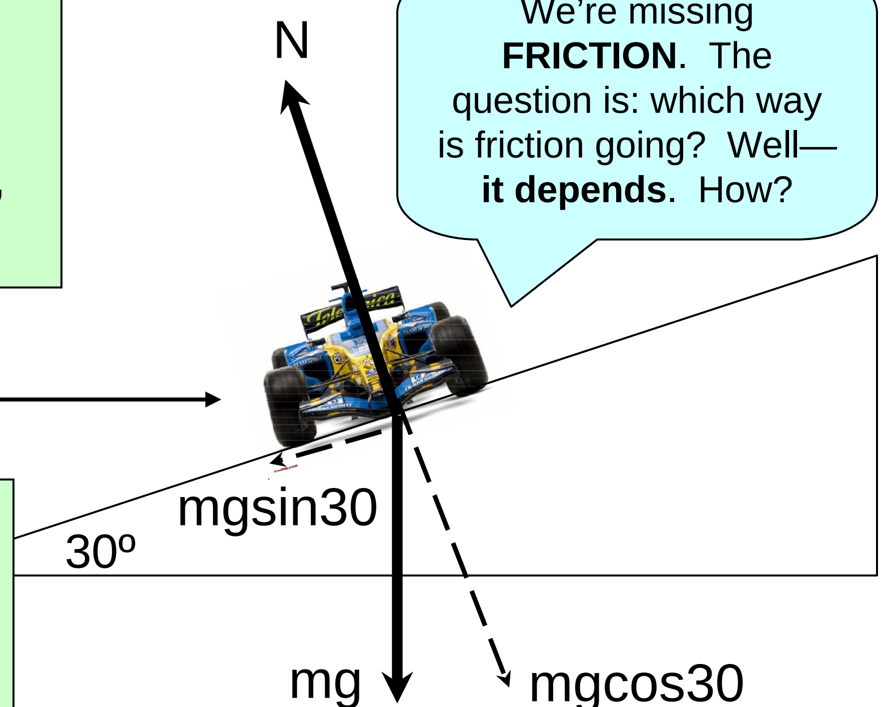
So let's first consider the free body diagram of the Formula One car on the banked turn. Remember, this is an **inclined plane**.

We're missing **FRICTION**. The question is: which way is friction going? Well— **it depends**. How?

200 m



Note that friction is STATIC (NOT KINETIC), because the car is not initially moving in the direction of the incline. Hence, it's good that we have the coefficient of STATIC friction.

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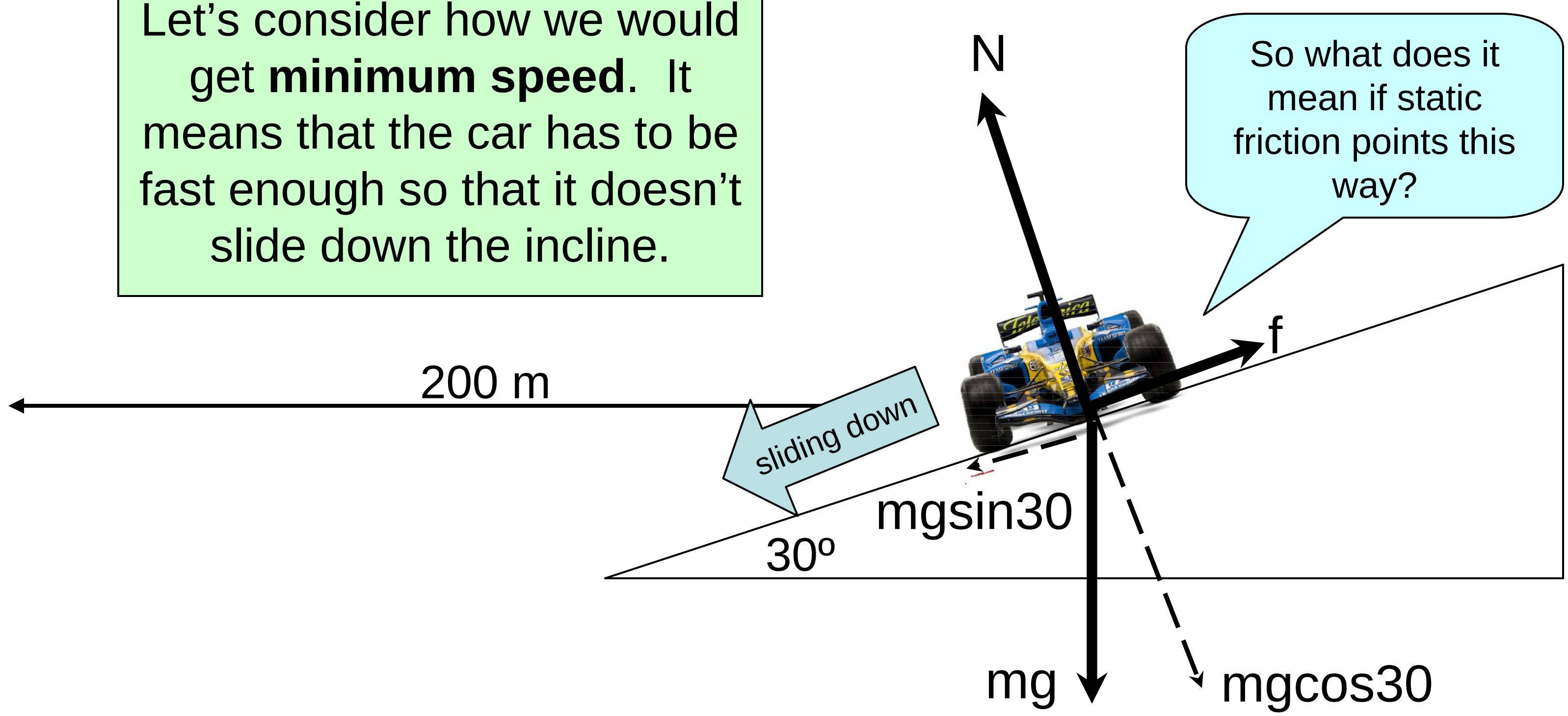
Let's consider how we would get **minimum speed**. It means that the car has to be fast enough so that it doesn't slide down the incline.



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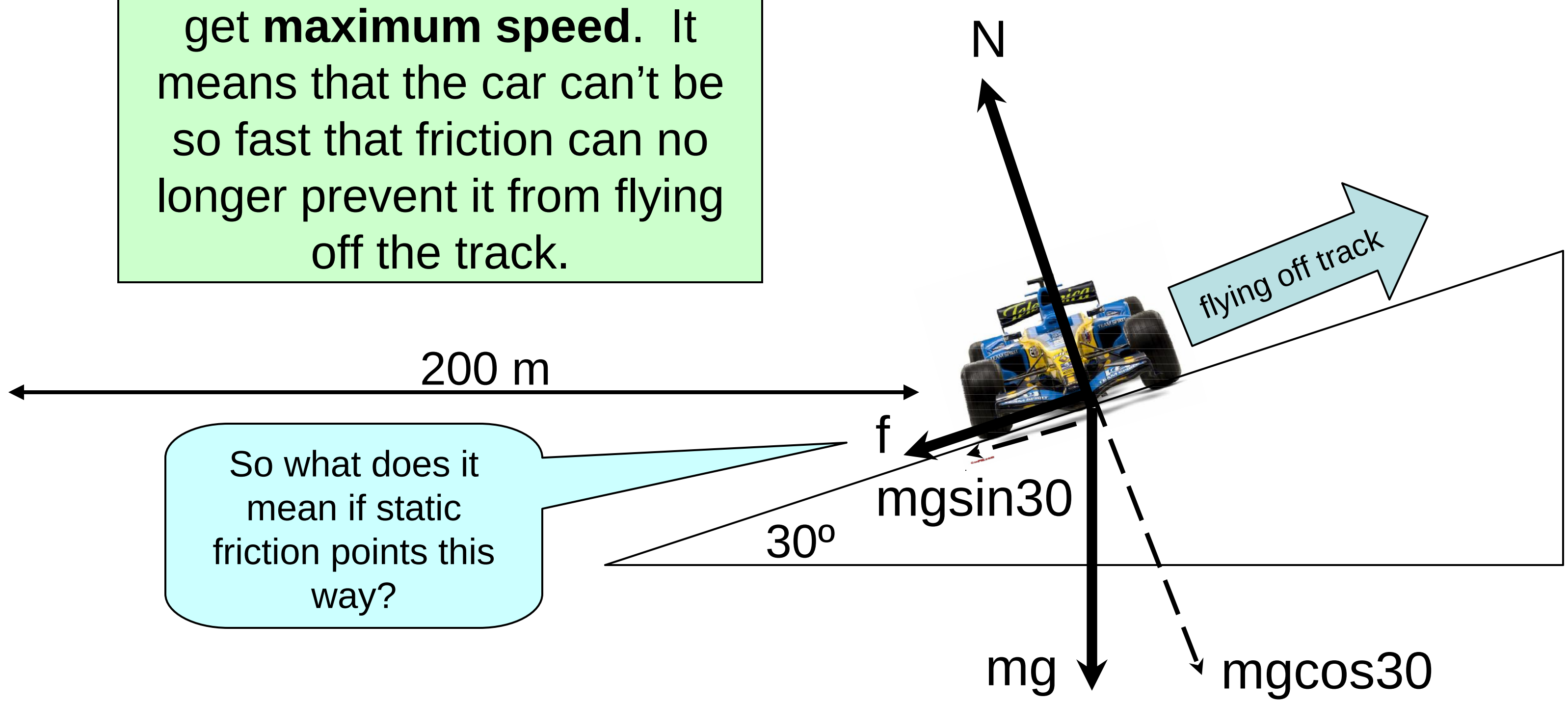
Let's consider how we would get **maximum speed**. It means that the car can't be so fast that friction can no longer prevent it from flying off the track.



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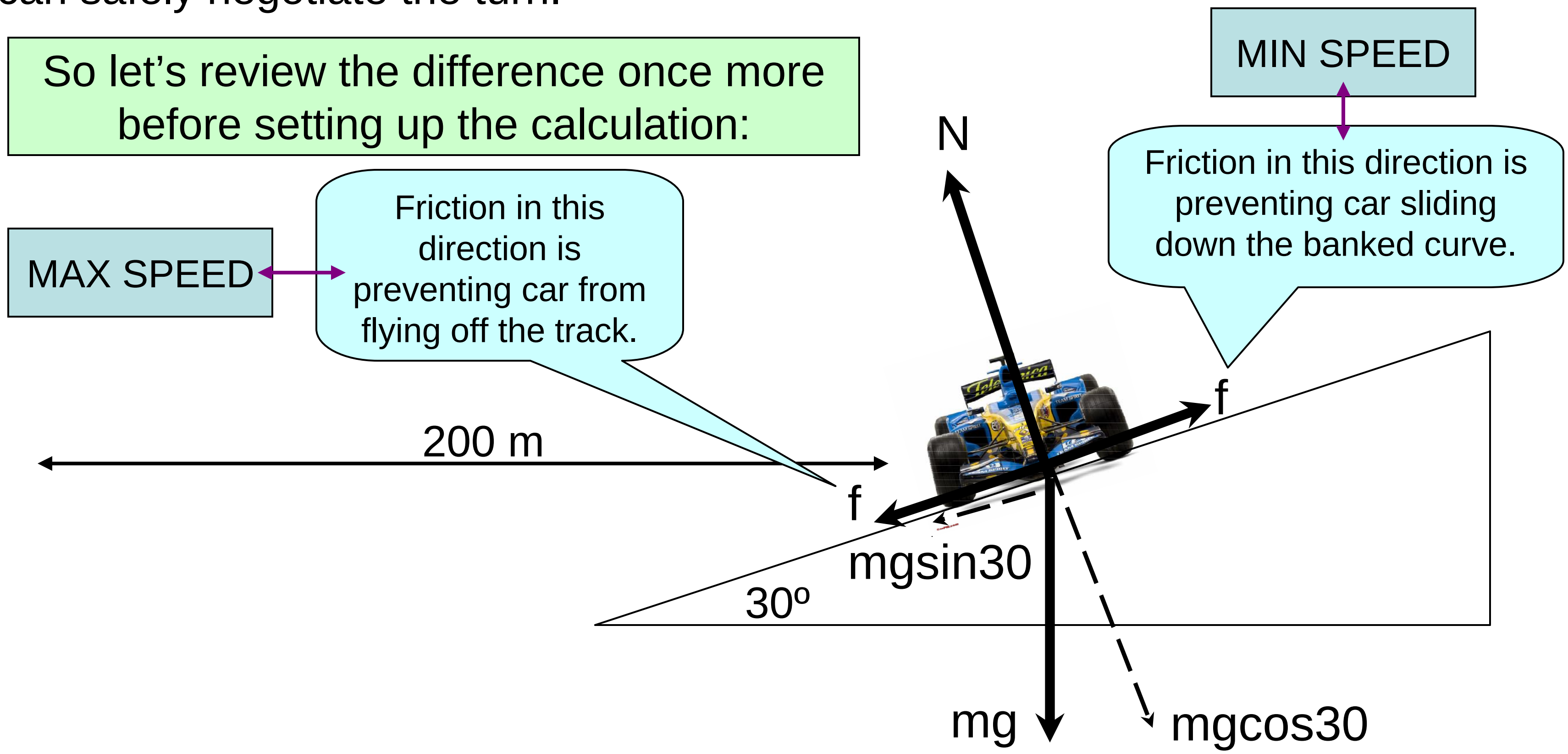
So let's review the difference once more before setting up the calculation:



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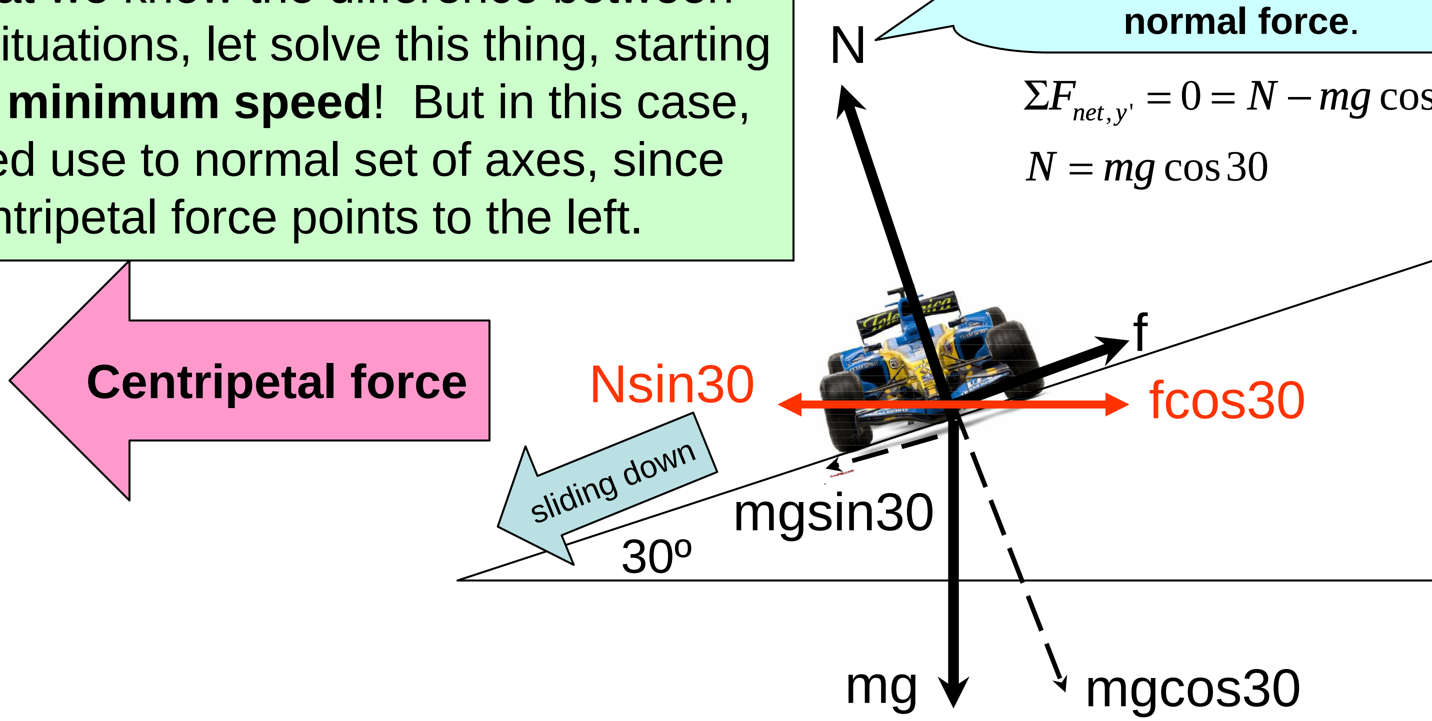
Now that we know the difference between the two situations, let solve this thing, starting with the **minimum speed**! But in this case, we need use to normal set of axes, since centripetal force points to the left.

We can use the conventional inclined plane axes to find the **normal force**.

$$\Sigma F_{net,y'} = 0 = N - mg\cos 30$$

$$N = mg\cos 30$$



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$$\Sigma F_{net,x} = \frac{mv_{\min}^2}{R} = N\cos 30 - f\cos 30$$

$$\Sigma F_{net,x} = \frac{mv_{\min}^2}{R} = N\cos 30 - mN\cos 30$$

$$\Sigma F_{net,x} = \frac{mv_{\min}^2}{R} = (mg\cos 30)\sin 30 - m(mg\cos 30)\cos 30$$

Note that mass cancels out from both sides.

Solving for the **minimum speed**:

$$\frac{mv_{\min}^2}{R} = (mg\cos 30)\sin 30 - m(mg\cos 30)\cos 30$$

$$\frac{v_{\min}^2}{R} = (g\cos 30)\sin 30 - m(g\cos 30)\cos 30$$

$$v_{\min}^2 = Rg(\cos 30\sin 30 - m\cos^2 30)$$

$$v_{\min} = \sqrt{(200m)(9.8m/s^2)(0.866\cdot 0.500 - 0.50\cdot 0.866^2)}$$

$$v_{\min} = 10.66m/s$$

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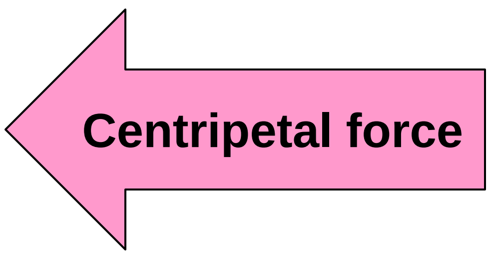
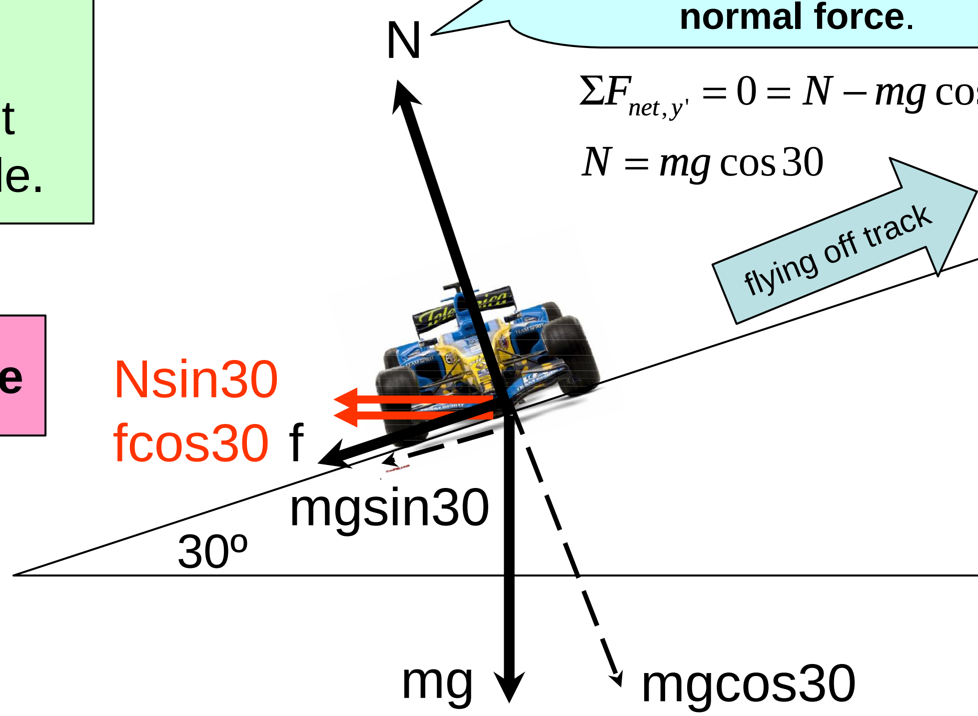
We can use the conventional inclined plane axes to find the **normal force**.

$$\Sigma F_{net,y'} = 0 = N - mg\cos 30$$

$$N = mg\cos 30$$

In order to find the **maximum speed**, remember that we put friction on the other side.





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$$\Sigma F_{net,x} = \frac{mv_{\max}^2}{R} = N\cos 30 + f\cos 30$$

$$\Sigma F_{net,x} = \frac{mv_{\max}^2}{R} = N\cos 30 + \mu N\cos 30$$

$$\Sigma F_{net,x} = \frac{mv_{\max}^2}{R} = (mg\cos 30)\sin 30 + \mu(mg\cos 30)\cos 30$$

Note that every step of the set-up is the same EXCEPT the friction component is ADDED instead of SUBTRACTED

Solving for the **maximum speed**:

$$\frac{mv_{\max}^2}{R} = (mg\cos 30)\sin 30 + \mu(mg\cos 30)\cos 30$$

$$\frac{v_{\max}^2}{R} = (g\cos 30)\sin 30 + \mu(g\cos 30)\cos 30$$

$$v_{\max}^2 = Rg(\cos 30\sin 30 + \mu\cos^2 30)$$

$$v_{\max} = \sqrt{(200m)(9.8m/s^2)(0.866\cdot 0.500 + 0.50\cdot 0.866^2)}$$

$$v_{\max} = 39.80m/s$$