

## Particles on a slope (with Friction)

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Here, as in leaflet 2.7, particles on a slope are considered, but this time including friction.

### Worked Example 1.

If a particle, of mass  $M$  kg, is on the point of slipping down a rough plane that is inclined at an angle  $\theta$  to the horizontal, what is the coefficient of friction?

#### Solution

Resolving perpendicular to the plane:

$$R = Mg \cos \theta$$

Resolving parallel to the plane:

$$F = Mg \sin \theta$$

As the particle is on the point of slipping, friction is limiting,  $F = F_{MAX}$ , so:

$$\begin{aligned} F &= \mu R \\ Mg \sin \theta &= \mu \times Mg \cos \theta \\ \frac{Mg \sin \theta}{Mg \cos \theta} &= \mu \end{aligned}$$

$$\tan \theta = \mu \quad \text{Note: } \tan \theta = \frac{\sin \theta}{\cos \theta}$$

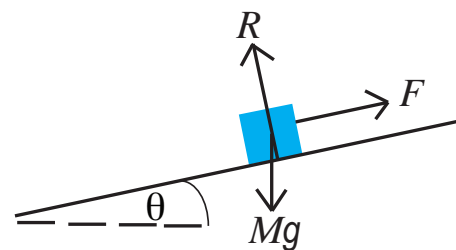


Figure 1

This can be written as  $\theta = \arctan \mu$ ;  $\theta$  is referred to as the **Angle of Friction**.

### Worked Example 2.

A box of mass 6 kg is on the point of slipping down a rough slope, which is inclined at an angle  $30^\circ$  to the horizontal. A force  $S$  is applied to the box and acts up the plane. Given that the coefficient of friction is 0.45, what is the magnitude of  $S$ ? (Figure 2 shows the forces acting on the box, when modelled as a particle.)

#### Solution

Resolving perpendicular to the plane:

$$R = 6g \cos 30^\circ$$

Resolving parallel to the plane:

$$F = 6g \sin 30^\circ - S$$

As the box is on the point of slipping, friction is limiting,  $F = F_{MAX}$ , so:

$$\begin{aligned} F &= \mu R \\ 6g \sin 30^\circ - S &= 0.45 \times 6g \cos 30^\circ \\ S &= 6g \sin 30^\circ - 0.45 \times 6g \cos 30^\circ = 6.5 \text{ N (2 s.f.)} \end{aligned}$$

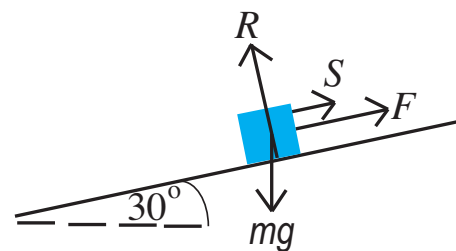


Figure 2

### Worked Example 3.

A ski is dropped by a skier ascending a ski slope. The ski begins to slide down the slope, which is inclined at an angle  $25^\circ$  to the horizontal. Given the ski has a mass  $m$  kg and the coefficient of sliding friction between the ski and the slope is 0.21, what is the acceleration of the ski? (Figure 3 shows the forces acting on the ski, when modelled as a particle.)

#### Solution

As the motion is down the slope, the sum of the perpendicular forces equals zero.

Resolving perpendicular to the plane:

$$R = mg \cos 25^\circ$$

As the ski is sliding, the frictional force is given by:

$$F = \mu R = 0.21 \times mg \cos 25^\circ$$

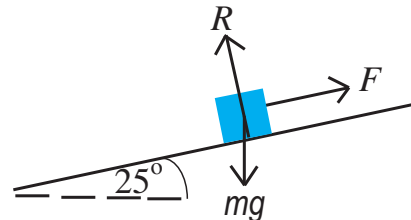


Figure 3

Use Newton's Second Law, parallel to the plane. The resultant force is  $mg \sin 25^\circ - F$ :

$$\begin{aligned} mg \sin 25^\circ - 0.21 \times mg \cos 25^\circ &= ma \\ a &= g \sin 25^\circ - 0.21 \times g \cos 25^\circ = 2.3 \text{ m s}^{-2} \text{ (2 s.f.)} \end{aligned}$$

### Exercises

1. If a particle, of mass 11 kg, is on the point of slipping down a rough plane that is inclined at an angle  $16^\circ$  to the horizontal, what is the coefficient of friction?
2. A box of mass 5 kg is on the point of slipping down a rough slope, which is inclined at an angle  $12^\circ$  to the horizontal. A force  $S$  is applied to the box and acts up the plane. Given friction is acting and the coefficient of friction is 0.12, what is the magnitude of  $S$ ?
3. A ski is dropped by a skier ascending a ski slope. The ski begins to slide down the slope, which is inclined at an angle  $22^\circ$  to the horizontal. Given the ski has a mass 2 kg and the coefficient of sliding friction between the ski and the slope is 0.19, what is the acceleration of the ski?
4. If a particle, of mass  $m$  kg, is on the point of slipping down a rough inclined plane that has a coefficient of friction of 0.14, what is the angle of the incline from the horizontal?
5. A box of mass 4 kg is on the point of slipping down a rough slope, which is inclined at an angle  $40^\circ$  to the horizontal. A force  $S$  of magnitude  $\frac{1}{4} R$  (where  $R$  is the normal reaction force) is applied to the box and acts up the plane. Given friction is acting, what is the coefficient of friction?
6. A ski is dropped by a skier ascending a ski slope. The ski begins to slide down the slope, which is inclined at an angle  $15^\circ$  to the horizontal. Given the ski has a mass  $m$  kg and has an acceleration of  $1.2 \text{ m s}^{-2}$ , what is the coefficient of sliding friction between the ski and the slope?

### Answers (all to 2 s.f.)

1. 0.29   2. 4.4 N   3.  $1.9 \text{ m s}^{-2}$    4.  $8.0^\circ$    5. 0.59   6. 0.14