You should refer to the *Glossary* if you are unsure about the meaning of *projectile* or *parabolic*. Parabolas are discussed more fully in the maths strand of *FLAP*.

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The word *unbalanced* is included here because bodies that are *not* accelerating may be acted upon by several opposing forces that cancel each other out.

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Notice that Equation 1

$$\boldsymbol{F} = m\boldsymbol{a} \qquad \text{(Eqn 1)}$$

also denies the common misconception that an object moves in the direction of the unbalanced force acting on it. It is the *acceleration* not the motion which is in the direction of the unbalanced force – a projectile motion under gravity illustrates this point.

It is only when an object starts from rest or experiences an unbalanced force in the direction of its imotion that it moves in the direction of the unbalanced force.

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The *position vector* of a point is a vector that describes the position of the point relative to some origin of coordinates. So the length of the vector represents the distance between the point and the origin and the direction of the vector is the direction from the origin to the point. Here we are taking the centre of the circle as the origin. These ideas are discussed fully in the maths strand of *FLAP*.

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Equation 2

$$s = r\theta \qquad \text{(Eqn 2)}$$

will *not* hold true if θ is measured in degrees.

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Notice in Equation 3a

$$\langle v \rangle = \frac{s}{t} = \frac{r\theta}{t} = r\langle \omega \rangle \qquad \text{(Eqn 3a)}$$

that s denotes distance measured along the arc, *not* the speed.

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The derivative notation is fully discussed in the maths strand of *FLAP*.

Mathematicians usually write this as

$$\lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

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Instantaneous speed and instantaneous angular speed are sometimes abbreviated to speed and angular speed respectively.

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Remember, ω must be in radians per second!

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Vector notation is fully discussed in the maths strand of *FLAP*.

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$\Delta v_{AB} = |\Delta \boldsymbol{v}_{AB}|$

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Note that although the magnitude of a velocity is a speed, the magnitude of the vector representing the *change* in velocity does not represent a change of *speed*. The speed is unchanged in uniform circular motion.

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Remember, ω must be in radians per second!

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Experiments show that it requires a larger force to cause an object to *begin* to slip, compared to that required to *maintain* slippling. There are two coefficients of friction — that for *static friction* and the lower one for *dynamic friction*, after slipping has occurred. In our example here, before slipping occurs the car is rolling but not slipping and so it is the coefficient of static friction which is involved. *Friction* is discussed more fully elsewhere in *FLAP*.

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Remember, we are treating the Earth as a perfect sphere in this idealized discussion.

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This equation and *Newton's law of gravitation* are developed more fully elsewhere in *FLAP*.

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Of course, the planets aren't really in *circular* orbits, but for many purposes the elliptical orbits of the planets can be approximated by circles.

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Sometimes the word *geosynchronous* is used more generally to describe any satellite that completes an orbit in 24 hours even if that orbit is inclined relative to the Equator. A satellite in such an inclined orbit will not appear ‘fixed’ in the sky but it will return to any given position after a 24 h period. *Geostationary* is always used to refer to satellites that appear to maintain a fixed position in the sky.

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✧

The only significant force which the satellite experiences is that due to the Earth's gravitational attraction. Its direction is always towards the centre of the Earth — and therefore towards the centre of the circle which describes the satellite's orbit. At all points in the orbit, the direction of the satellite's motion is tangential, i.e. acting along a tangent to the circle. Since the force is radial, i.e. directed towards the centre of the circle, and the motion is tangential, it follows that at all points in the orbit the force acting on the satellite is perpendicular to its direction of motion. ❑

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The force acting on the satellite arises from the gravitational attraction of the Earth. Later, in Subsection 4.2, we will discuss this quantitatively. For the moment we need to accept only that this force decreases in some way as distance from the Earth increases. Since in this case this distance is constant, it is reasonable to assume that the force has a constant magnitude. ❑

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✧

The force responsible for the circular motion is the *tension* in the elastic due to the stretching of the elastic. ❑

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You will know from experience that the tension in an elastic band increases as it is stretched. If the pencil rubber is moving with constant speed in a circle, the elastic will always have the same length, so the magnitude of the force it exerts on the pencil rubber will be constant. The direction of the force is obviously along the elastic and pulling inwards towards the centre of the circle. If the speed is increased the radius and the tension will increase as the elastic stretches more. ❑

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As with the satellite discussed in the previous example, the motion is tangential while the force is radial with respect to the circle. So once again, the force is everywhere perpendicular to the direction of motion. ❑

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ω is the angle (in radians) covered per second and 2π radians represents one complete revolution. So the time required for one revolution, the period T, is

$$T = \frac{2\pi}{\omega} \qquad (5)$$ ❑

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