2

FORCE AND NEWTON'S LAWS OF MOTION

2.1 Problems

2.1 A courier is delivering a 5 kg package to an office high in a tall building.

(a) What upwards force does the courier apply to the package when carrying it horizontally at a constant velocity of 2 m s^{-1} into the building?

(b) The courier uses the elevator to reach the office. While the elevator (containing the courier who is holding the package) is accelerating upwards at 0.11 m s^{-2} what upwards force is the courier applying to the package?

(c) When the elevator is traveling upwards at a constant speed of 6 m s^{-1} what upwards force does the courier apply to the package?

(d) In order to stop at the correct floor the elevator accelerates downwards (decelerates) at a rate of 0.20 m s^{-2}. What is the upwards force the courier applies to the package during the deceleration?

Answer: (a) Taking upwards as the positive direction, $F_{\text{app}} = 50$ N, (b) $F_{\text{app}} = 50.55$ N, (c) $F_{\text{app}} = 50$ N, d) $F_{\text{app}} = 49$ N

2.2 You live at the top of a steep (a slope of 15° above the horizontal) hill and must park your 2200 kg car on the street at night.

(a) You unwisely leave your car out of gear one night and your handbrake fails. Assuming no significant frictional forces are acting on the car, how quickly will it accelerate down the hill?

(b) The increase in insurance premiums due to the results of your mistake mean that you cannot afford to fix your handbrake properly. You resolve to always leave your car in gear when parked on a slope. If the rolling frictional force caused by leaving the drive-train connected to the wheels is 5000 N, at what rate will your car accelerate down the hill if the handbrake fails again?

Answer: (a) $a = 2.6$ m s^{-2}
(b) $a = 0.32$ m s^{-2}

2.3 You are pulling your younger sister along in a small wheeled cart. You weigh 65.0 kg and the combined mass of your sister and the cart is 35.0 kg. You are pulling the cart via a short rope which you pull horizontally. You hold one end of the rope and your sister holds the other end. If you are accelerating at a rate of 0.10 m s^{-2}, the rope is inelastic, and the frictional force acting upon the cart is 30 N:

(a) What is the tension in the rope?

(b) What force are you applying to the ground in order to produce this acceleration?

Answer: (a) $T = 34$ N.
(b) You apply a force of 40 N to the ground.

2.4 Two flexible balls rolling along a frictionless horizontal surface collide with each other. The larger of the balls weighs 50 g and the smaller weighs 30 g. Immediately after the balls first touch each other (the beginning of the collision), the center of mass of the larger ball is accelerating at a rate of 5 m s^{-2} to the right. What is the acceleration of the center of mass of the smaller ball? Answer: 8.3 m s^{-2} to the left.

2.5 The Earth has a mass of 5.97×10^{24} kg and the Moon has a mass of 7.36×10^{22} kg. The average distance between the center of the Earth and the center of the Moon is 3.84×10^{8} m.

(a) What is the gravitational force acting on the Moon due to the Earth?

(b) What is the gravitational force acting on the Earth due to the Moon?

(c) How far away would the Moon need to be for the magnitude of the gravitational force acting on it due to the Earth be the same as the magnitude of the gravitational force of a 72 kg student sitting at their desk on the surface of the earth?

(c) A supermassive black hole passes through the edge of the solar system 1.20×10^{13} m away. The gravitational force between an observant 79 kg astronomer and the black hole is 1 N. What is the mass of the black hole?

Answer: (a) 1.99×10^{20} N towards the Earth (b) 1.99×10^{20} N towards the Moon (c) 2.04×10^{17} m (this is 21.6 light years!) (d) 2.7×10^{34} kg (1400× more massive than the sun)

2.6 A 4 kg vase of flowers is placed directly in the middle of a glass table. The glass tabletop itself weighs 8 kg. With what force do each of the four legs of the table push on the glass after the vase has been placed on top? Answer: 30 N