

## Exercises 1.3

Thus, the differential equation is

$$x \frac{d^2 x}{dt^2} + \left( \frac{dx}{dt} \right)^2 + 32x = 160.$$

20. The force is the weight of the chain,  $2L$ , so by Newton's second law,  $\frac{d}{dt}[20x] = 2L$ . Since the mass of the portion of chain off the ground is  $m = 2(L - x)/g$ , we have

$$\frac{d}{dt} \left[ \frac{2(L-x)}{g} v \right] = 2L \quad \text{or} \quad (L-x) \frac{dv}{dt} + v \left( -\frac{dx}{dt} \right) = Lg.$$

Thus, the differential equation is

$$(L-x) \frac{d^2 x}{dt^2} - \left( \frac{dx}{dt} \right)^2 = Lg.$$

21. From  $y = k/R^2$  we find  $k = gR^2$ . Using  $a = d^2 r/dt^2$  and the fact that the positive direction is upward we get

$$\frac{d^2 r}{dt^2} = -a = -\frac{k}{r^2} = -\frac{gR^2}{r^2} \quad \text{or} \quad \frac{d^2 r}{dt^2} + \frac{gR^2}{r^2} = 0.$$

22. The gravitational force on  $m$  is  $F = -kM_r m/r^2$ . Since  $M_r = 4\pi\delta r^3/3$  and  $M = 4\pi\delta R^3/3$  we have  $M_r = r^3 M/R^3$  and

$$F = -k \frac{M_r m}{r^2} = -k \frac{r^3 M m / R^3}{r^2} = -k \frac{m M}{R^3} r.$$

Now from  $F = ma = d^2 r/dt^2$  we have

$$m \frac{d^2 r}{dt^2} = -k \frac{m M}{R^3} r \quad \text{or} \quad \frac{d^2 r}{dt^2} = -\frac{k M}{R^3} r.$$

23. The differential equation is  $\frac{dA}{dt} = k(M - A)$ .  
 24. The differential equation is  $\frac{dA}{dt} = k_1(M - A) - k_2 A$ .  
 25. The differential equation is  $x'(t) = r - kx(t)$  where  $k > 0$ .

26. By the Pythagorean Theorem the slope of the tangent line is  $y' = \frac{-y}{\sqrt{x^2 - y^2}}$ .

27. We see from the figure that  $2\theta + \alpha = \pi$ . Thus

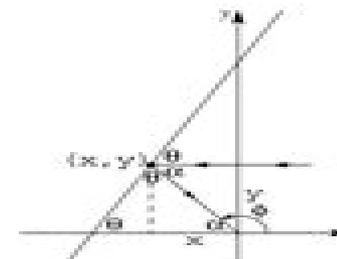
$$\frac{y}{-x} = \tan \alpha = \tan(\pi - 2\theta) = -\tan 2\theta = -\frac{2 \tan \theta}{1 - \tan^2 \theta}.$$

Since the slope of the tangent line is  $y' = \tan \theta$  we have  $y/x = 2y'[1 - (y')^2]$  or  $y - y(y')^2 = 2xy'$ , which is the quadratic equation  $y(y')^2 + 2xy' - y = 0$  in  $y'$ . Using the quadratic formula we get

$$y' = \frac{-2x \pm \sqrt{4x^2 + 4y^2}}{2y} = \frac{-x \pm \sqrt{x^2 + y^2}}{y}.$$

Since  $dy/dx > 0$ , the differential equation is

$$\frac{dy}{dx} = \frac{-x + \sqrt{x^2 + y^2}}{y} \quad \text{or} \quad y \frac{dy}{dx} - \sqrt{x^2 + y^2} + x = 0.$$



28. The differential equation is  $dP/dt = kP$ , so from Problem 29 in Exercises 1.1,  $P = e^{kt}$ , and a one-parameter family of solutions is  $P = ce^{kt}$ .

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