Week 1a:

Intro, Slope Fields, verify solution

1.4 Separable DE, Cooling

1.5 population

1.6 Linear Equations

Week 1b: 1.7 Mixing

Problem:

Inflamable substance, temp $T_0 = 50$ (F), placed in hot oven, temp $T_m = 450$ (F). After 20 min substance temp $T = 150$. Find temp at 40 min. If substance ignites at 350, find time of combustion.

Solution:

Newton's Law of cooling: $T = T(t)$ temp at time t,

$$\frac{dT}{dt} = -k(T - T_m), \quad T_m = 450,\ t \text{ in min.}$$

$\dfrac{dT}{dt} = -k(T - T_m)$, $T_m = 450, T(0) = 50, T(20) = 150$,

find $T(40)$ and t_c so $T(t_c) = 350$. **Method:** separation.

$$\frac{dT}{T - T_m} = -k\,dt, \quad (T \neq T_m).$$

integral: $\ln|T - T_m| = -k\,t + c$, $T_m = 450$.

Initial Data: $\ln(450 - T) = -k\,t + c$,

$T(0) = 50, T(20) = 150$.

When $t = 0$, $\ln 400 = c$, $e^c = 400$. So $450 - T = e^{-kt}e^c$

$= 400e^{-kt}$, and $T = T(t) = 450 - 400\,(e^{-k})^t$.

Next, when $t = 20$, $150 = 450 - 400\,(e^{-k})^{20}$,

so $-300 = -400\,(e^{-k})^{20}$, $e^{-k} = (\frac{3}{4})^{\frac{1}{20}}$,

and $T(t) = 450 - 400\,(\frac{3}{4})^{\frac{t}{20}}$.

Finally, $T(t) = 450 - 400\,(\frac{3}{4})^{\frac{t}{20}}$, gives

$T(40) = 225$, and $T(t_c) = 350$ gives $t_c = 96.4$ minutes.

(why?)

For $t = 40$, $\frac{t}{20} = 2$, then $(\frac{3}{4})^2 = \frac{9}{16}$ and

$400 * \frac{9}{16} = 25 \cdot 9 = 225$, so $T(40) = 450 - 225 = 225$.

Next, for $T := t \to 450 - 400 * ((3/4)^{(t/20)})$; Maple's

fsolve(T(t)=350,t); gives $t_c = 96.3768$.

Problem: A 200L tank is half full of a solution containing 100g of a desolved chemical. A solution containing 0.5 g/L of the same chemical is pumped into the tank at a rate of 6 L/min. The well-stirred mixture is pumped out at a rate of 4 L/min. Determine the concentration of the chemical in the tank just before overflow.

Solution:

$V = V(t)$ and $A = A(t)$ will be the volumn of the solution in the tank (in L) and amount of chemical in the tank (in g), at time t (in min.). The "rate in" is, $r_1 = 6$ and "rate out", $r_2 = 4$; and the "concentration in" is, $c_1 = 0.5$, while we solve for the "concentration out", $c_2 = \dfrac{A}{V}$.

First, the initial volumn $V_0 = 100$ (one half of the tank's volumn), so $V(t) = 100 + (r_1 - r_2)t = 100 + 2t$ ("rate in" - "rate out"). Next, the tank overflows when V is 200, which occurs when $t = 50$, (why?) so we're looking for $c_2(50)$. Now our main DE says that the rate of change of the amount of the chemical, $\frac{dA}{dt}$, is the difference $r_1c_1 - r_2c_2$ ("rate in" - "rate out"), which we re-write as

$$\frac{dA}{dt} + \left(\frac{4}{100+2t}\right) A = 3, \text{ (using } c_2 = \tfrac{A}{V}\text{)}.$$

Now $\dfrac{dA}{dt} + \left(\dfrac{4}{100+2t}\right) A = 3$ is a Linear DE,

with coefficient $P = \dfrac{4}{100+2t} = \dfrac{2}{50+t}$.

So $\displaystyle\int P\,dt = 2\ln(50+t) = \ln(50+t)^2$,

and the integral factor $I = e^{\int P\,dt} = e^{\ln(50+t)^2}$

$= (50+t)^2$. Multiplying both sides by I and using

the Main Property gives

$$\tfrac{d}{dt}\left((50+t)^2 A\right) = 3(50+t)^2,$$

then integrating gives $(50+t)^2 A = (50+t)^3 + c$, so

$$A = 50 + t + \frac{c}{(50+t)^2}.$$

One last bit of data, the initial amount of the chemical

was 100g, which gives the initial condition $A(0) = 100$,

so $100 = 50 + \dfrac{c}{50^2}$, and $c = 50^3$,

$A(t) = 50 + t + \dfrac{50^3}{(50+t)^2}$.

So from $A(t) = 50 + t + \dfrac{50^3}{(50+t)^2}$, we have

$c_2(50) = \dfrac{A(50)}{V(50)} = \dfrac{100 + \frac{125000}{100^2}}{200}$

$= \dfrac{100 + \frac{125}{10}}{200} = \dfrac{100 + \frac{25}{2}}{200}$

$= \dfrac{\frac{225}{2}}{200} = \dfrac{225}{400} = \dfrac{9}{16}$ g/L for the

concentration at the time of overflow.

Population [off homework!]

Logistic model: $P = P(t)$ pop. at time t,

$\frac{dP}{dt} = r(1 - \frac{P}{C})P$ where C is the carrying capacity (asymptotic limit (max) population), and r is the birth rate per individual; t in years.

Key Step in method: After $C\,dP = r(C-P)P\,dt$,

separation gives $\dfrac{C\,dP}{(C-P)P} = r\,dt$,

where we use Partial Fractions to get

$$\frac{C}{(C-P)P} = \frac{A}{P} + \frac{B}{C-P}$$

with $A = B = 1$, so $\displaystyle\int \left(\frac{1}{P} + \frac{1}{C-P}\right) dP = rt + c_1$,

where the integral is $\ln P - \ln(C-P) = \ln \dfrac{P}{C-P}$.

Not-so Key Steps: Raising to e gives $\dfrac{P}{C-P} = e^{rt}e^{c_1}$,

where we replace e^{c_1} by c_2, and solve for P, then

use the initial condition to replace c_2 by $\dfrac{P_0}{C-P_0}$

and clear fractions to get the solution in a

standard form.

Problem Setup: In practice, we don't

use formulas, and simply observe that

if the maximum population, the carrying capacity,

is everyone, say $C = 1500$, and the DE is

$\dfrac{dP}{dt} = kP(1500-P)$, we solve using

Partial Fractions, without needing any other formulas.