Problem Set #9 1.725 Fall 2004 solutions

4-5, 6, 14, 36, 37

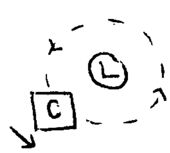
5. dry adiabatic lapse rate: 9.8°C/1000m

A line that starts from the actual temperature at ground level, with a slope equal to the dry adiabatic lapse rate, intersects the temperature profile at a height of ~600m. A parcel of air at this height will not continue to rise, because it would be colder and denser than the surrounding air, causing it to then sink back down.

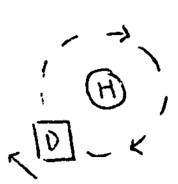
⇒ thus, the mixing height is ~600m

6. a) Region A is more likely to experience precipitation. The cold front means that warmer air is uplifted; this air mass cools adiabatically, so if the moisture content exceeds the (lowered) vapor pressure, water will condense. There is also a low pressure area near region A which can explain the same effects.

b) Region C: There is a low-pressure area nearby, which tends to cause formation of a cyclone. In the Northern Hemisphere, wind is counterclockwise around the low, so at point C the wind is probably towards the southeast.



Region D. high pressure (anticyclone) → wind is clockwise → towards northwest

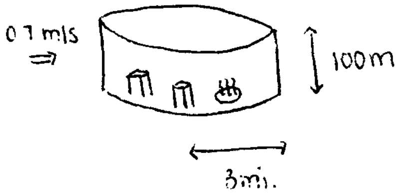


On a more local scale, Region D may also experience a sea breeze. During the day, wind will be from sea to land (adding to the synoptic circulation); at night, wind will be from land to sea (going against the synoptic circulation). This is because the water warms + cools more slowly → warm air rises → displaced by cooler air.

c) Region F is more likely to have air pollution. In the core of an anticyclone, air moves downward and warms adiabatically. This sometimes leads to an inversion, which will inhibit mixing and trap pollutants near the ground.

At E, there will be more mixing as the cold and warm air masses meet, causing pollution to be spread out. The cold front is also associated with clouds and precipitation, which can remove pollutants from the atmosphere through wet deposition processes.

14. We can use a box model for this urban area, since there is a well-defined mixing height and winds are light (see p. 3-17).



80 kg TCA released during 8-hour shift
(10 kg/hr)

input − output + Σ sources − Σ sinks = $\frac{dC}{dt} \cdot V = 0$ at steady state

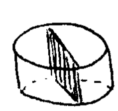
(we have only sources and output here)

Σ sources = output

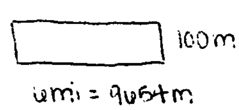
$= ACH \cdot V \cdot C$ just like the indoor problems

$= \left(\frac{u \cdot area}{V}\right) V \cdot C$ * see p. 3-17; note that dividing by V is necessary to get the correct units (1/time)

$= u \cdot area \cdot C$



cross-sectional area



$$C = \frac{\Sigma\, sources}{u \cdot area}$$

$$= \frac{10\ kg/hr\ (hr/3600\ s)}{0.7\ m/s\ (9.65 \times 10^{5}\ m^2)}$$

$$= 4.1 \times 10^{-9}\ kg/m^3 = \boxed{4.1 \times 10^{-3}\ \mu g/L}$$

b) The primary sink is probably reaction with the ·OH radical (photo-oxidation). TCA may also be removed through wet deposition (due to partitioning into water) or sorption onto surfaces such as plants

3u. input − output + Σ sources − Σ sinks = 0 at steady state

a) $C_{out} \approx 0$, so no input

$-C_{in} \cdot V \cdot ACH + \Sigma sources - k \cdot C_{in} \cdot V = 0$

$k = \frac{\ln 2}{3.8\,d} = \frac{0.182}{d} \times \frac{d}{24h} = .0076\,h^{-1}$

$\Sigma sources = C_{in} \cdot V (ACH + k)$

$ACH = \frac{\Sigma sources}{C_{in} \cdot V} - k = \frac{0.1 \times 10^{-4}\ Ci/hr}{(4 \times 10^{-12}\ Ci/L)(15{,}000\,L)} - .0076\,hr^{-1} = \boxed{1.66\ hr^{-1}}$

At this ventilation rate, the sink term (radioactive decay) doesn't make much of a difference − the radon is getting transported out of the room much faster than it can decay.

b) also no sinks

$C_{in} \cdot V \cdot ACH = \Sigma sources$

$C_{in} = \frac{7 \times 10^{-4}\ g/hr}{(15{,}000\,L)(0.05\,hr^{-1})} = \boxed{9.3 \times 10^{-7}\ g/L}$

c) back to the mass balance equation from part a:

$\Sigma sources = C_{in} \cdot V (ACH + k)$

$C_{in} = \frac{\Sigma sources}{V(ACH + k)} = \frac{10^{-7}\ Ci/hr}{15{,}000\,L\,\underbrace{(0.05\,hr^{-1} + .0076\,hr^{-1})}_{}} = \boxed{1.2 \times 10^{-10}\ Ci/L}$

now the ventilation and decay rates are close enough that decay can't be neglected

note. it may not be immediately obvious how to express the sink term. From the complete mass balance equation [4-14], but only looking at the sinks, we have:

$-\Sigma sinks = \frac{d\,C_{in} \cdot V}{dt}$

we also have the standard first-order decay equation:

$\frac{dc}{dt} = -kC$

Rearrange and set the two dc/dt expressions equal:

$\frac{-sinks}{V} = -kC \Rightarrow \Sigma sinks = k \cdot C \cdot V$

$\boxed{37.}$ Initial conditions, 4000 m, -13°F, in cloud ($\therefore$ wet adiabat)

We want to know what altitude the pilot must descend to in order to reach temperatures above 32°F. Using the skew T - log P diagram, we find this occurs at ~2500 m. Since some of the mountains are as high as 3000 m, this is not a safe plan.