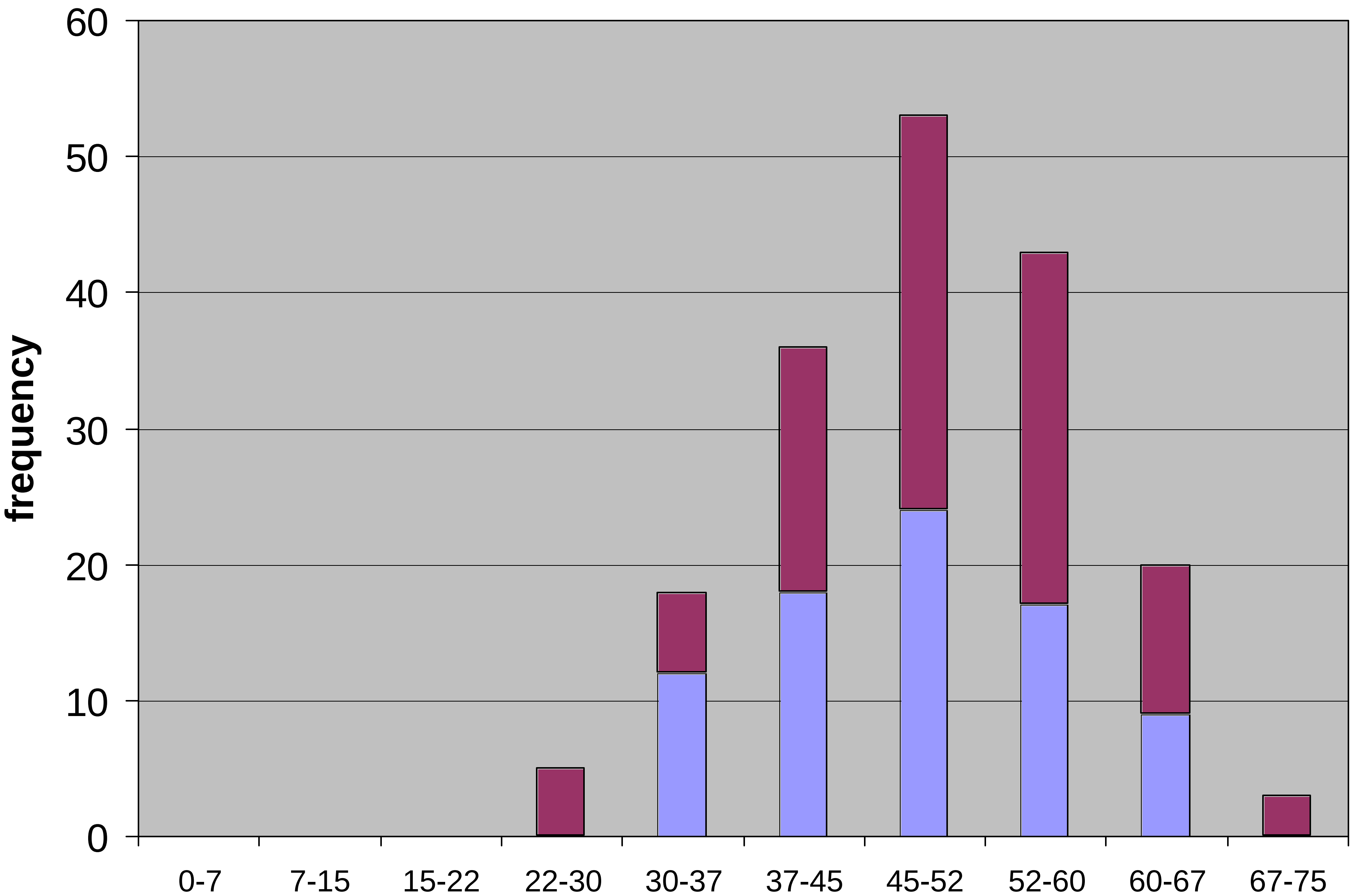


frequency
0
10
20
30
40
50
60
0-7
7-15
15-22
22-30
30-37
37-45
45-52
52-60
60-67
67-75

name: **SOLUTION**

Closed book/notes; 50 minutes; 75 points.

1. *(25 pts)* Short answer. **Put answers in spaces provided.**

a) Approximately how much air does an adult inhale per day? **~ 15 m^3 (5-30 m^3)** *(1)*

Approximately how much water does an adult ingest per day? **~ 2 L (1-8 L)** *(1)*

Give a limitation in assessing human health risk using results from each of the following.

animal studies: **extrapolation across species and to low dose**

epidemiologic studies: **statistical not causal; confounding issues** *(2)*

What are the two leading causes of death in the U.S.?

(1) heart attack **(2) cancer** *(2)*

b) Biomass fuels have a similar carbon intensity (gC/MJ) as coal. So why is their use proposed as a means to reduce global warming? **consumes CO2 when grown** *(1)*

On an energy basis, is natural gas, oil, coal or uranium most abundant? **uranium** *(1)*

On an energy basis, is natural gas, oil, coal or uranium most used? **oil** *(1)*

Energy intensity (MJ/GDP) in the U.S. and Canada is higher than in many European countries with similar standard of living. Give two reasons why this might be so.

(1) low population density – greater need to transport goods

(2) less efficient; more wasteful – e.g. large cars, excessive heating & cooling *(2)*

True or false. Since the 1970s, U.S. per capita energy consumption has been steady. **true** *(1)*

c) At what rate is the atmospheric CO_2 concentration increasing? **~ 2 ppm/yr (0.5-4 ppm/yr)** *(1)*

List three strategies for stabilizing or reducing CO_2 levels in the atmosphere.

(1) switch fuels – C ¯ **(2) sequester – capture/store** **(3) reduce demand – eff. -** *(3)*

In addition to CO_2, identify two other greenhouse gases.

(1) CH4 **(2) N2O (also CFCs)** *(2)*

True or false. Increased airborne particles have had a net cooling effect on the earth. **true** *(1)*

How much earth warming (°C) has been observed since 1800? **~ 0.8 °C (0.4-2 °C)** *(1)*

d) Approximately what percentage of water cycling between the earth and atmosphere is available via runoff from land to ocean? **~ 8% (1-15%)** *(1)*

What two processes govern water transfer from the earth to the atmosphere?

(1) evaporation **(2) transpiration** *(2)*

e) True or false. Since ambient air quality monitoring began in Atlanta in 1970, …

… increased vehicle use has resulted in higher ambient CO levels. **false**

… increased energy use has resulted in higher ambient SO_2 levels. **false** *(2)*

name: **SOLUTION**

2. *(30 pts)* Short problems (mass). **Show all work, and put answers in spaces provided.**

a) Worldwide, estimate the annual carbon emissions from production of $2\text{x}10^6$ MW of electricity from coal. Use the following average data: 40% power plant efficiency, 30 MJ/kg net heating value, 80% (mass) carbon content, 99% carbon emission. (W = J/s)

$2\text{x}10^6$ MW / 0.4 / 30 MJ/kg x 0.8 x 0.99 = $1.32\text{x}10^5$ kgC/s
$1.32\text{x}10^5$ x 60 x 60 x 24 x 365 = $4.16\text{x}10^{12}$ kgC/yr

Answer (A/B/C/D): $4.16\text{x}10^{12}/4.38\text{x}10^{12}/4.63\text{x}10^{12}/4.90\text{x}10^{12}$ kgC/yr *(4)*

The total mass of the atmosphere is about $5\text{x}10^{18}$ kg. If all of the emitted carbon calculated above remained in the atmosphere as CO_2, what would be the annual increase in CO_2 concentration (ppm). MW data: air = 29 g/mol (average); C = 12 g/mol; O = 16 g/mol

$4.16\text{x}10^{12}$ kgC/yr / $5\text{x}10^{18}$ kg x 10^6 = 0.83 ppm (mass)
0.83 x 29 / 12 = 2.01 ppm (vol)

Answer (A/B/C/D): 2.01/2.12/2.24/2.37 ppm(vol)/yr *(4)*

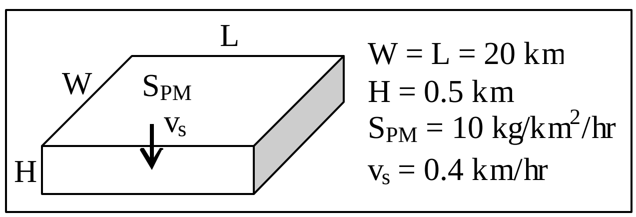
b) Diesel fuel (a pure hydrocarbon with H/C molar ratio of 1.6) is burned in 40% excess air (21% O_2 and 79% N_2). Calculate the air-to-fuel mass ratio, first writing the combustion reaction of fuel and air going to CO_2, H_2O, N_2, and O_2.
Atomic mass (g/mol): C = 12, H = 1, O = 16, N = 14

combustion rxn: $CH_{1.6} + 1.96\ (O_2 + 79/21\ N_2) \rightarrow 1\ CO_2 + 0.8\ H_2O + 0.56\ O_2 + 7.37\ N_2$

(1.96 x 32 + 1.96 x 3.76 x 28) / (12+1.6) = 19.8

Answer (A/B/C/D): 19.8/21.2/22.6/24.0 kg-air/kg-fuel *(8)*

c) In the well mixed urban airshed shown at right, there is an area PM emission source (S_{PM}) and a sink due to settling (settling velocity v_s). There is no wind (in or out). Write a steady state mass balance equation, then solve for PM concentration ($\mu g/m^3$).



PM mass balance eq: $0 = 0 - 0 + A\ S - v_s\ A\ C$

$C = S / v_s = 10 / 0.4 = 25$ kg/km^3 = 25 μg/m^3

Answer (A/B/C/D): 25/33/50/100 μg/m^3 *(8)*

For a sudden reduction in the source emission, write an unsteady PM mass balance equation. Provide a characteristic time (hr) for the change in PM concentration, and define its meaning.

PM mass balance eq: $V\ dC/dt = A\,S - v_s\ A\ C$

$dC / (S/v_s - C) = V/(v_s\ A)\ dt = H/v_s\ dt \rightarrow t_{ch} = H/v_s = 0.5/0.4 = 1.25$ hr

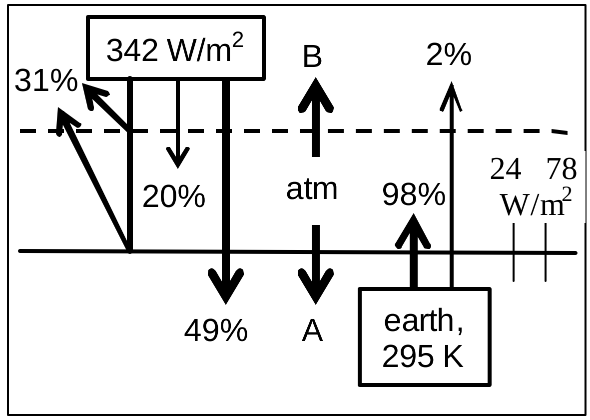
Answer (A/B/C/D): t_{ch} = 1.3/1.7/2.5/5.0 hr

definition: time to reach 63% of new steady state *(6)*

 name: **SOLUTION**

3. *(20 pts)* Energy balance problems. **Show all work, and put answers in spaces provided.**

a) Write steady-state energy balances for the earth-atmosphere system shown at right, which includes radiative fluxes (sun, atmosphere and earth) and convective and evaporative fluxes (24 and 78 W/m^2). For the incoming solar energy (342 W/m^2), percentages reflected and absorbed and transmitted by the atmosphere are shown. The earth radiates as a blackbody (σT^4 where $\sigma = 5.67\times10^{-8}$ W/m^2/K^4), with percentages absorbed by the atmosphere and escaping to space shown. Its temperature is given. The atmosphere radiates differently to earth (A) and to space (B). Estimate the temperatures of the upper and lower atmosphere, assuming it radiates as a gray body ($\varepsilon \sigma T^4$ where $\varepsilon = 0.98$).



Earth energy balance equation: **$0.49\,S + A = E + 24 + 78$** *(4)*

Atmosphere energy balance equation: **$0.2\,S + 0.98\,E + 24 + 78 = A + B$** *(4)*

$E = 5.67\times10^{-8} \times (295)^4 = 429.4$ W/m^2

$A = 363.8$ W/m^2 → $T_{lower\ atm} = (363.8/0.98/5.67\times10^{-8})^{1/4} = 284$ K

$B = 227.4$ W/m^2 → $T_{lower\ atm} = (227.4/0.98/5.67\times10^{-8})^{1/4} = 253$ K

A/B/C/D: $T_{upper\ atm}$ = 253/252/251/250 K

A/B/C/D: $T_{lower\ atm}$ = 284/284/283/282 K *(4)*

b) In a diesel engine, isentropic compression ($PV^{1.4}$ = constant) of air occurs with a compression ratio, V_1/V_2, of 13. For air intake conditions of P_1 = 1 atm and T_1 = 300 K, calculate the temperature after compression and before combustion (T_2).
Ideal gas law: $PV = nRT$

isentropic process: $P_2 = P_1 (V_1/V_2)^{1.4} = 1 \times (13)^{1.4} = 36.3$ atm

ideal gas law: $T_2 = T_1 (P_2/P_1)(V_2/V_1) = 300 \times 36.3 / 13 = 837$ K

A/B/C/D: T_2 = 837/862/886/909 K *(4)*

Fuel is injected (air-to-fuel mass ratio = 20) and combustion occurs at constant pressure. Using an average gas specific heat (c_p) of 1100 J/kg/°C and a net fuel heating value of 45 MJ/kg, calculate the gas temperature increase from combustion without heat loss ($T_3 - T_2$).

$E_{fuel} = m_{fuel} \times 45\times10^6$ J/kg $= E_{air} = m_{air} \times 1100$ J/kg/°C $\times\ \Delta T$

$\Delta T = (m_{fuel}/m_{air}) \times 45\times10^6 / 1100 = (1/20) \times 45\times10^6 / 1100 = 2045$ °C

$T_3 - T_2$ = 2045 °C *(4)*