

1. Greenhouse Gases (50 pts: 12, 8, 20, 10)

a) Circle each of the following gases that absorb infrared radiation: CO₂, O₂, CH₄, O₃, N₂O, N₂

+3 pts each for correct answers (x4 = 12), -1 pt each for a wrong one circled

b) Assess the following statements about the Earth's albedo. +2 pts for each right (x4 = 8)

c) Answer the following questions about the Earth's radiation balance.

i) Give an expression for the incoming solar radiation at the top of the Earth's atmosphere in terms of the solar constant (S_0) and the albedo (α_p).

+5pts for: $0.25 \cdot S_0(1 - \alpha_p)$, +3pts for something close, -1 or -2 if additional incorrect parts

ii) Give an expression for the outgoing black body radiation of the Earth, assuming no atmosphere.

+5pts for: σT_e^4 , +3pts for something close, -1 or -2 if additional incorrect parts

iii) Given conservation of energy, how are the quantities in (i) and (ii) related?

+5pts for $0.25 \cdot S_0(1 - \alpha_p) = \sigma T_e^4$ or "equal"

ii) Is the no-atmosphere Earth colder than reality or warmer? Why?

+3pts for "Colder" and +2pts for "no greenhouse effect" or if it is well described, +1pt for no greenhouse gases or no atmosphere and if the greenhouse effect is not mentioned.

d) What is the thermodynamic basis for knowing that global warming results from increased CO₂?

Full Credit:

+3pts for "first law of thermodynamics" and +5pts for "energy is conserved" or "conservation of energy" and +2pts for "increased absorption by CO₂ will result in higher temperatures" = 10pts

Partial Credit Points:

+2pts for any mention of CO₂ absorbing IR or longwave radiation

+2pts for an energy balance equation

+1pt for CO₂ is a greenhouse gas

2. Chapman Cycle (50 pts: 20, 12, 18)

a) Write the four reactions of the Chapman Cycle.

+5pts for each correct equation (x4 = 20)

-1 pt for each missing or additional wrong species up to 5pts per equation

b) Name the three factors needed to calculate the rate constant (j) for the photolysis reactions in part (a). Which of these factors varies the most with altitude? Why?

Full Credit: 3pts each for quantum yield, absorption cross section, and photon flux

+2pts for photon flux varies most and +1pt for the correct reason

Partial Credit:

-1pt if "absorption" is missing

-1 or -2pts if they are close but wrong (ex: cross sectional area)

e) Assess if the following statements are true or false. +3 pts for each right (x6 = 18)

3. Ozone Hole (39 pts: 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3) +3 pts for each right (x13 = 39)

4. Atmospheric Composition (61 pts: 10, 20, 10, 10+4, 6)

a) For each volume composition or mixing ratio (or range) in the atmosphere listed below, pick the component that is found in that amount in the *atmosphere at the surface in 2010*:

CO₂, CH₄, O₂, CFC-11, O₃, SF₆, N₂O, N₂, Ar, H₂O.

+2pts each for the right pairing (x5 = 10). No points if it was blank or wrong.

b) From the list of components in Question 4(a), answer the following:

i) Which component(s) of the atmosphere has a distinct layer of high concentration in the stratosphere?

+4pts for O₃ and -1pt for each wrong species

ii) Which component(s) can act as a greenhouse gas?

+5pts for 7/7 correct (this makes this question 21 pts, not just 20pts),

+4pts for 6/7 correct, +3pts for 5/7 and 4/7 correct, +2pts for 3/7 correct,

+1pt for 2/7 and 1/7 correct, AND -1pt for each wrong one included

iii) Which component(s) are noble gases? +4pts for Ar and -1pt for each wrong species

iv) Which component is observed in three different phases in atmospheric conditions? +4pts for H₂O and

-1pt for each wrong species

v) Which components have no natural sources? +4pts for CFC-11 and -1pt for each wrong species

c) If the mass of the atmosphere is 5×10^{18} kg and if CFC-11 makes up $0.2 \times 10^{-9}\%$, what is the mass of CFC-11 in the atmosphere? ($MW_{\text{CFC-11}} = 137$, $MW_{\text{air}} = 29$ g/mole). For simplicity you may assume $137/29 \approx 5$.

Full Credit: +10pts for the correct answer and the correct units

Partial Credit:

-1pt for a math error, IF all work is shown and clear

-1pt for the wrong answer, -1pt for NO answer, -1pt for wrong units, -1pt for no units

-1pt for each additional unnecessary value included in the calculation (i.e. Avogadro, etc.)

+2pts for the correct units, if the answer was wrong and there was no work shown

+3pts each for: 0.2×10^{-9} CFC-11 molecules, 5 kg CFC-11/kg air, 5×10^{18} kg air

+1pt if the correct value was there, but it was flipped (i.e. divided, not multiplied)

+1pt for $1/10^2$ air molecules

d) What is the (minimum) residence time for an atmospheric constituent to be called "long-lived"?

+6pts for 1yr, +1pt for the wrong answer with "year" in it

Which of the species listed in 4(a) are long-lived?

+1pt each for the correct species (x8 = 8) and -1pt for each wrong species

e) Some of the "in situ" (or photochemical) atmospheric components are from natural sources and others are from man-made sources. For the in situ compounds below, specify which are mostly natural or man-made.

i) Stratospheric Ozone: +2pts

ii) Tropospheric Ozone: +2pts

iii) NO₂: +2pts