EAS 3603 - Thermodynamics of Earth Systems

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PART 1: INTRODUCTION

Introduction

- What is thermodynamics? Why study thermodynamics of the Earth system?
- Thermodynamic systems: composition and state; system vs the environment; open or closed or isolated; boundaries of a system and the environment,
- Thermodynamic state of a system: state variables (intensive and extensive); thermodynamic properties; equation of state
- State variables: pressure, temperature, volume/density; units

Composition and structure of components of the earth system

- Composition: atmosphere, ocean, solid earth
- Pressure: units; vertical variations in the atmosphere, ocean, solid earth; space/time variability
- Density (specific volume): units; vertical variations in the atmosphere, ocean, solid earth
- Temperature: units; vertical variations in the atmosphere, ocean, and solid earth; space/time variability
- Hydrostatic equation: application to ocean and hypothetical constant density atmosphere; solid earth

Equation of state

- Ideal gas law
- Kinetic-molecular model of the ideal gas
- Equation of state for air: Dalton's law of partial pressures; virtual temperature
- Hypsometric equation (atmosphere)
- Equation of state for real gases, liquids, and solids
- Equation of state for seawater

PART 2: FRAMEWORK

First Law of thermodynamics

- Basic concepts
- Mathematical review: differentials and derivatives, exact differentials
- Work; expansion work
- Heat: heat capacity, basics of heat transfer mechanisms
- First law of thermodynamics: internal energy, enthalpy, specific heats, heat capacity.
- Applications of first law to ideal gases: Poisson's relations

Entropy and the 2nd law

- Entropy: reversible and irreversible processes; Clausius inequality; Boltzmann-Gibbs statistical picture of entropy
- 2^{nd} Law of thermodynamics
- First and second laws combined: Legendre transformations: Gibbs and Helmholtz functions; thermodynamic equilibrium
- Thermodynamic relations: Maxwell relations; relations involving specific heats
- Adiabatic processes in the dry atmosphere, ocean, and mantle and core
- Static stability
- Entropy and diffusive processes (heat conduction, viscosity, etc)
- Entropy, heat, and the 3^{rd} law

Phase Equilibria

- Gibbs phase rule: thermodynamic degrees of freedom, phases and components
- Energy in phase changes and chemical reactions
- Phase equilibria: chemical potential and multicomponent systems (Gibbs-Duhem); latent heat; Clapeyron equation (first latent heat law) and Kirchoff's equation (second latent heat law)
- Application to water (single component system): phase diagram; Clausius-Clapeyron equation;
- Binary phase diagrams (water solution): simple eutectics, lever rule
- Crystallization in binary systems: equilibrium crystallization, fractional crystallization, melting

PART 3: APPLICATIONS

Moist thermodynamic processes in the atmosphere

- Humidity variables
- Isobaric cooling: dew point and frost point; radiation fog
- Cooling and moistening by evaporation of water: wetbulb temperature; prefrontal rain fog
- Saturation by adiabatic, isobaric mixing: steam fog and jet contrails
- Saturated adiabatic cooling: equivalent potential temperature; saturated adiabatic lapse rate, adiabatic liquid water content; convective cloud formation
- Aerological diagrams

Physical chemistry of water solutions – solution thermodynamics

- Fugacity and activity
- Ideal solutions
- Colligative properties
- (Real solutions: variation of activities)
- Aeorosols (deliquescence-efflourescence; surface energy-Kelvin effect; applications using ISORROPIA)

Petrology

- geothermometry and geobarometry
- melting beneath mid-ocean ridges and composition of oceanic crust
- magmatic fractionation and layered intrusions