28 July 2006

ASTM001/MAS423 SOLAR SYSTEM (Semester B, 2006/7)

I. General Course Aims and Learning Outcomes

- Aims:
  - To introduce and explain the mathematical tools and physical concepts used in the study of the Solar System.
  - To introduce and illustrate the use of dynamical and constitutive equations for understanding the structure and evolution of the Solar System and its constituents.
  - To reinforce some of the material encountered in earlier and concurrent, related courses – e.g., *Calculus II* and *III*, *Dynamics of Physical Systems*, and *Astrophysical Fluid Dynamics*.
  - To provide experience in solving intermediate-level problems in Solar System physics using analytical techniques previously encountered or introduced in the course.

- Learning Outcomes:

  By the end of the course, the successful student should:

  - Be able to name and locate the planets, major moons, major belts, and boundary of the Solar System and to explain Kepler's laws.
  - Have a good feel for the size, time, mass, and other physical scales associated with the Solar System and the objects that compose it.
  - Understand how mathematical models of the Solar System and its constituents are constructed, including understanding the simplifications and limitations inherent in the constructed models.
  - Gain mastery in the use of physical concepts and mathematical techniques to solve intermediate-level problems involving one-, two-, and (restricted) three-particle motions.
  - Gain mastery in the use of physical concepts and mathematical techniques to solve intermediate-level problems involving fluid motions, solid mechanics, and energy and momentum transport.

II. Syllabus (with specific Learning Outcomes for each lecture)

- **Lecture 1: General Overview and Survey**
  - Inventory: Sun, terrestrial planets, giant planets, satellites, asteroids, ring systems, and heliosphere
  - Planetary Properties: Orbit, mass, size, rotation, shape, and temperature, atmospheric, surface, and interior structures.

  Learning Outcomes

  By the end of this lecture, the successful student should:
  1. Be familiar with the structure, contents, and overall expectations of the course.
  2. Be able to name and locate the Sun, planets, major moons, asteroid and Kuiper belts, Oort cloud, and heliopause.
  3. Acquire a sense for the size, time, mass, and energy scales of the Sun, planets, major moons, and asteroids.

- **Lecture 2: Two-Body Problem**
  - Kepler's Laws
  - Elliptical motion and orbital elements
  - Parabolic and hyperbolic orbits

  Learning Outcomes

  By the end of this lecture, the successful student should:
  1. Be able to describe and derive Kepler's three laws.
  2. Be able to name and describe the six orbital elements that uniquely specify the Keplerian orbit.
  3. Be able to distinguish between bound and unbound orbits and use the bound/unbound orbit concept to solve simple elliptical, parabolic, and hyperbolic orbit problems.

- **Lecture 3: Restricted Three-Body Problem**
  - Jacobi constants and Lagrange points
  - Horseshoe and Tadpole orbits
  - Hill sphere

  Learning Outcomes

  By the end of this lecture, the successful student should:
  1. Be able to derive the Jacobi constant and to describe and locate the five Lagrange points for a test particle in a restricted three-body problem.
  2. Be able to explain Horseshoe and tadpole orbits and to solve simple problems pertaining to these orbits.
  3. Be able to explain the concept of Hill sphere and solve simple problems using this concept.

- **Lecture 4: Perturbation, Resonance, and Dissipation**
  - Perturbed Kepler motion
  - Jacobi-Hill stability
  - Dissipative Forces: Poynting-Robertson drag, Yarkovsky effect, and particle and gas drag

  Learning Outcomes

  By the end of this lecture, the successful student should:
  1. Be able to analyse a simple mathematical example of perturbation problem and to explain the general concept of perturbation in Keplerian motion.
  2. Be able to analyse a simple mathematical model of resonance and to give an example of orbital resonance.
  3. Be able to explain the concept of Jacobi-Hill stability and to derive the functional form of the stability criterion.
  4. Be able distinguish and explain radiation pressure, Poynting-Robertson drag, Yarkovsky effect, and Epstein drag

- **Lecture 5: Oblateness and Tides**
  - Gravitational potential
  - Precession around oblate bodies
  - Tidal torque and dissipation

  Learning Outcomes

  By the end of this lecture, the successful student should:
  1. Be able to describe the gravitational potential of an axisymmetric planet in terms of Legendre polynomials and explain the "J_n coefficients", the gravitational moments.
  2. Be able to explain the precession of particle orbits about an oblate planet.
  3. Be able to analyse the bulge, torque, and dissipation caused by tidal force and to solve simple problems related to these effects.

- **Lecture 6: Planetary Interiors**
  - Interior modelling theory
  - Heat sources, losses, and transport
  - Survey of the interior structures of planets and moons

  Learning Outcomes

  By the end of this lecture, the successful student should:
  1. Be able to determine the internal structure of a spherical body using hydrostatic equilibrium, constitutive relations, and equation of state.
  2. Be able to explain several possible sources of heat as well as mechanisms to transport the energy, ultimately to lose to space.

- **Lecture 7: Planetary Surfaces**
  - Magma physics
  - Tectonics and weathering
  - Impact cratering

  Learning Outcomes

  By the end of this lecture, the successful student should:
  1. Be able to explain phase diagrams of a melt and the general sequence of reactions in a cooling magma.
  2. Be able to discuss the concept of plate tectonics and the atmospheric effects of water, wind, and chemicals on landscape morphology.
  3. Be able to discuss the morphology, dynamics, and excavation of impacts and estimate scales and energetics associated with impacts.

- **Lecture 8: Planetary Atmospheres**
  - Vertical (thermal and compositional) structures
  - Hydrodynamic equations, Geostrophy, and atmospheric (Rossby and gravity) waves

  Learning Outcomes

  By the end of this lecture, the successful student should:

  1. Be able to describe the basic thermal and wind structures of the Earth and compare them with structure information known for other planets with atmospheres.
  2. Be able to explain the terms in the *primitive equations* of meteorology and to explain and use the concept of geostrophy.
  3. Be able to derive and analyse the dispersion relations for Rossby and gravity waves.

- **Lecture 9: Sun-Planet Interaction**
  - Radiative equilibrium and global energy budget
  - Greenhouse effect
  - Photodissociation and ionisation below the magnetosphere

  Learning Outcomes

  By the end of this lecture, the successful student should:

  1. Be able to estimate the equilibrium temperatures of the planets in the Solar System and become familiar with the global-mean energy budget of the Earth as an example of land-ocean-atmosphere system interacting with the Sun.
  2. Be able to analyse a simple model of the greenhouse effect and relate the concept of greenhouse effect to the current state of the atmospheres on Venus, Earth, and Mars.
  3. Be able to explain the major photochemical processes that establish the basic thermal structure of the middle/upper atmosphere on Venus, Earth, and Jupiter.

- **Lecture 10: Meteorites, Asteroids, and Comets**
  - Meteorite classification and identification
  - Asteroid orbit and size distributions
  - Comet orbits, reservoirs, and structure
  - Connection to the formation of the Solar System

  Learning Outcomes

  By the end of this lecture, the successful student should:

  1. Be able to discuss the classification of meteorites based on their thermal history and the identification of meteorites by their extraterrestrial origin.
  2. Be able to discuss the distributions of the semimajor axes of asteroid orbits and the sizes of asteroids.
  3. Be able to describe the basic structure and physical properties of a comet.
  4. Be able to explain the connections of meteorites, asteroids, and comets to the formation and evolution of the Solar System.

- **Lecture 11: Planetary Rings**
    - Tidal forces and Roche's limit
    - Flattening and spreading
    - Interactions with moons

Learning Outcomes

By the end of this lecture, the successful student should:

1. Be able to understand tidal disruption and its relationship to the formation of planetary rings.
2. Be able to explain how collisions of ring particles lead to settling of the ring into the planet's equatorial plane and the spreading of the ring.
3. Be able to understand and analyse the dynamics of resonances, waves, and shepherding in rings.

- **Lecture 12: Planet Formation**
    - Evolution of the protoplanetary disc and growth of solid bodies
    - Formation of terrestrial and giant planets
    - Planet Migration

Learning Outcomes

By the end of this lecture, the successful student should:

1. Be able to describe the history of the protoplanetary disc, divided into three basic stages of infall, internal evolution, and clearing.
2. Be able to explain the current ideas about dynamics in the final stages of planetesimal accumulation, planetary differentiation, and net accumulation of volatiles in planetary atmospheres.
3. Be able to compare and contrast the gas-instability and core-instability hypotheses of giant planet formation.
4. Be able to understand the different types of orbital migration.