Notes on Newtonian Mechanics

1 Preliminaries

Mechanics: study of behavior of objects with respect to geometry and timing of motion, force, and energy

- Measurable (vector/scalar) quantities, Measurement uncertainty (significance arithmetic)
- Dimensions/Units (base units, derived units, dimensionless derived units) (unit arithmetic)

2 Kinematics

Kinematics: study of how objects move with respect to geometry and timing

- Reference frames, Coordinate systems, the Calculus of motion (position, velocity, acceleration, etc.)
- Translational/Rotational motion, Relative motion (Galilean relativity, later: Einsteinian relativity)
- Constant acceleration (translational, rotational/angular) and changing acceleration
- Independence of motion in perpendicular directions

Examples

Projectile motion (parabolic motion)
Motion on/in moving fluids (air, water)
Uniform and non-uniform circular motion
Planetary/celestial motion (conic sections with perspective, Kepler's laws)

3 Dynamics

Dynamics: study of behavior of objects with respect to forces and energy; consists of kinetics and statics
Kinetics: study of how objects move with respect to forces and energy
Statics: study of forces and energy involved when objects are at rest

- Newton's Laws of Motion (translational form $\Rightarrow$ systemic, rotational forms)
  - N1 Inertia, N2 Net Force, N3 Coaction
  - Inertial reference frames, mass, velocity, momentum, acceleration, force
- System (set of physical objects: 1 or more particles, rigid bodies, etc.), Isolated $\Rightarrow$ no external forces
  - N2 for a system $\rightarrow$ Center of mass (kinematics/dynamics)
- Net impulse $\overset{\text{N2}}{=}$ Change in momentum
- N2+N3 $\Rightarrow$ Mutual net forces (force pairs, "coaction") between two systems over time imply exchange of momenta (equal and opposite impulse)
  - No net external forces on a system $\Rightarrow$ <u>Conservation</u> of total momentum of system
- Definitions of Work/Energy, Kinetic energy $\overset{\text{N2}}{\Rightarrow}$ Work-(Kinetic) Energy Principle
  - No net work on a system $\Rightarrow$ <u>Conservation</u> of total kinetic energy of system
- Conservative Force/Work $\Rightarrow$ Potential energy (+ Kinetic energy $\equiv$ Mechanical energy)
  - Nonconservative Force/Work (dissipative static/kinetic friction; at times, normal forces)
  - Only conservative work done on system $\Rightarrow$ <u>Conservation</u> of mechanical energy of system
- Power (rate of work done or energy exchanged)
- Rotational motion
  - Moment of inertia, Angular momentum, Torque (Parallel axis theorem, Perpendicular axis theorem)
  - Work done by torque (Work-energy principle)
  - Power delivered through torque

- Statics: Zero net force ("mechanical equilibrium of the first kind"), Zero net torque ("... second kind")

Examples

Motion along surfaces, contact forces (with or without friction, ropes/pulleys)
Projectile motion (using energy, gravitational potential)
Rollercoaster or vehicle motion (with or without friction)
Collisions or break-up/explosion of projectile
  Conservation of momentum always assumed in collision or break-up (even when system isn't isolated)
  Degrees of elasticity: "super-elastic", perfectly elastic, inelastic, completely inelastic
  Kinetic energy is conserved only in (perfectly) elastic collisions, gained in super-elastic, lost in inelastic
  (super-elastic collisions are a.k.a. inelastic collisions of the 2nd kind,
  where the plain inelastic collisions are of the 1st kind)
Variable mass / Rocket propulsion, etc.
  (N2, using differential analysis and carefully choosing system) → thrust
Statics: ropes, pulleys, booms, hinges, frameworks, rigid bodies, etc.

4 Suggestions

- Word usage:
  - Be careful to distinguish between a word's (possibly various) technical and colloquial uses. In particular: *velocity*, *acceleration* (and *deceleration*), *inertia*, *momentum*, *force*, *impulse*, *elastic* (versus *perfectly elastic*), and *inelastic* (versus *completely inelastic*).
- Word problems:
  - Gather and organize information from sentences (put into pictures and/or diagrams, lists, charts)
  - They may not always state every assumption, so you may have to use some physical reasoning (come up with "no slipping" equation for wheels, etc.)
  - Be aware of and ponder simplifying assumptions such as considering ropes to be massless and not stretchable, or considering air drag to be negligible for projectiles
- Problem-solving strategies:
  - The book has good tips; you should copy and memorize the tips, then put them into action
  - You should learn how to pick convenient reference frames (with convenient velocity, origin, and orientation) or axes (when dealing with rotation or torque), and convenient coordinate systems so that you reduce the amount of calculation
  - You should become familiar with the common mathematical techniques and tricks (catalogue them)
  - In dynamics, use free-body diagrams (a conceptual and mathematical setup)
- Activities:
  - Think about the concepts and ask questions!
  - Don't be afraid to ask basic questions; some of the deepest questions are very basic
  - (Be willing to take a small social risk and expose your thoughts, you'll advance more quickly that way and most likely help the quieter students)
  - Do lots of problems to induce questions and practice skills; untested knowledge is next to ignorance