Summary of Lecture 7

Key points include:

1. Kepler's laws were extremely successful, but they were also empirical. To understand them more deeply it was necessary to understand motion itself.
2. We'll start with definitions. *Position* is the three-dimensional location of something at a given instant. *Speed* is how fast that thing is moving at a given instant. *Velocity* is the speed *and direction* of motion of that thing at a given instant. *Acceleration* is the rate of change in velocity at a given instant. *Momentum* equals mass times velocity. *Force* changes momentum (in fact, force is the rate of change of momentum). There is also a rotational momentum (e.g., of something spinning or orbiting), which is called *angular momentum*.
3. Although colloquially we talk about them as the same, mass and weight are different. Mass is the amount of matter in an object. Weight is the gravitational force on that object. On the Moon, your mass would be the same but your weight would be different.
4. Isaac Newton used these concepts, and a whole lot of profound intuition, to come up with three laws of motion.
5. Newton's first law: an object moves at constant velocity unless a force acts to change its speed and/or direction. This is often called the "Law of inertia". Note: this means that even constant-speed motion (for example, constant speed in a circular orbit) requires a force if the direction changes.
6. Newton's second law: force equals mass times acceleration.
7. Newton's third law: for every action there is an equal and opposite reaction. Put another way, if thing A exerts a force on thing B, then thing B exerts the same magnitude of force on thing A, but in the opposite direction.
8. In addition, and partially stemming from Newton's laws, we understand that in an *isolated* interaction (i.e., nothing else is close enough to influence the things interacting), there are several quantities that are *conserved*, which means that they are the same before and after the interaction. Examples include mass and energy (Einstein showed that in a deep sense, mass is a form of energy), momentum, and angular momentum.
9. The angular momentum of an object around a given point equals the mass of the object times the distance of the object to the point, times the component of the velocity that is perpendicular to the object-point line. In symbols: $L = mvr$.

10. Angular momentum conservation is most familiar from ice skaters: with arms out (r is large), they twirl slowly (v is small), but when they bring their arms in (r becomes smaller) they twirl rapidly (v becomes larger), while their mass stays the same. Thus $L_{\text{before}} = L_{\text{after}}$.
11. Only an external torque (kind of like a twisting force) can change the angular momentum. Gravity from a point (say, from the Sun) exerts a force but not a twist, so planetary orbits have constant angular momentum if we ignore the weak forces from other planets.
12. Conservation of angular momentum, by itself, explains Kepler's second law: that the orbits of planets sweep out equal areas in equal times.