Spring Tides Essay, Research Paper

The tides at a given place in the Earth’s oceans occur about an hour later each day. Since the Moon passes overhead about an hour later each day, it was long suspected that the Moon was associated with tides. Newton’s Law of Gravitation provided a quantitative understanding of that association.

Differential Forces

Consider a water molecule in the ocean. It is attracted gravitationally by the Earth, but it also experiences a much smaller gravitational attraction from the Moon (much smaller because the Moon is much further away and much less massive than the Earth). But this gravitational attraction of the Moon is not limited to the water molecules; in fact, the Moon exerts a gravitational force on every object on and in the Earth. Tides occur because the Earth is a body of finite extent and these forces are not uniform: some parts of the Earth are closer to the Moon than other parts, and since the gravitational force drops off as the inverse square distance, those parts experience a larger gravitational tug from the Moon than parts that are further away.

In this situation, which is illustrated schematically in the adjacent figure, we say that differential forces act on the body (the Earth in this example). The effect of differential forces on a body is to distort the body. The body of the Earth is rather rigid, so such distortion effects are small (but finite). However, the fluid in the Earth’s oceans is much more easily deformed and this leads to significant tidal effects.

A Simple Tidal Model

We may illustrate the basic idea with a simple model of a planet completely covered by an ocean of uniform depth, with negligible friction between the ocean and the underlying planet, as illustrated in the adjacent figure. The gravitational attraction of the Moon produces two tidal bulges on opposite sides of the Earth. Without getting too much into the technical details, there are two bulges because of the differential gravitational forces. The liquid at point A is closer to the Moon and experiences a larger gravitational force than the Earth at point B or the ocean at point C. Because it experiences a larger attraction, it is pulled away from the Earth, toward the Moon, thus producing the bulge on the right side. Loosely, we may think of the bulge on the left side as arising because the Earth is pulled away from the water on that side because the gravitational force exerted by the Moon at point B is larger than that exerted at point C. Then, as our idealized Earth rotates under these bulges, a given point on the surface will experience two high and two low tides for each rotation of the planet.

More Realistic Tidal Models

The realistic situation is considerably more complicated:

The Earth and Moon are not static, as depicted in the preceding diagram, but instead are in orbit around the common center of mass for the system.

The Earth is not covered with oceans, the oceans have varying depths, and there is substantial friction between the oceans and the Earth.

These make a more realistic description much more complicated, but the essential ideas remains as illustrated in the preceding diagram. Here are realtime links to the present tidal conditions in San Francisco Bay and Houston-Galveston and here is a link to a set of graphs for the tidal levels over current 24-hour periods for various tidal stations. Notice in comparing these graphs the differences in the detailed tidal fluctuations for different locations (for example, compare the graph for Tacoma, Washington, with that for South Pass, Louisiana). These differences are produced by the complicating factors mentioned above.

Spring Tides and Neap Tides

Another complication of a realistic model is that not only the Moon, but other objects in the Solar System, influence the Earth’s tides. For most their tidal forces are negligible on Earth, but the differential gravitational force of the Sun does influence our tides to some degree (the effect of the Sun on Earth tides is less than half that of the Moon).

Competition between the Sun and Moon in producing tides.

For example, particularly large tides are experienced in the Earth’s oceans when the Sun and the Moon are lined up with the Earth at new and full phases of the Moon. These are called spring tides (the name is not associated with the season of Spring). The amount of enhancement in Earth’s tides is about the same whether the Sun and Moon are lined up on opposite sides of the Earth (full Lunar phase) or on the same side (new Lunar phase). Conversely, when the Moon is at first quarter or last quarter phase (meaning that it is located at right angles to the Earth-Sun line), the Sun and Moon interfere with each other in producing tidal bulges and tides are generally weaker; these are called neap tides. The figure shown above illustrates spring and neap tides.

Tidal Coupling and Gravitational Locking

We have introduced tides in terms of the effect of the Moon on the Earth’s oceans, but the effect is much more general, and has a number of important consequences that we will discuss further below. For example, as a consequence of tidal interactions with the Moon, the Earth is slowly decreasing its rotational period and eventually the Earth and Moon will have exactly the same rotational period, and these will also exactly equal the orbital period. Thus, billions of years from now the Earth will always keep the same face turned toward the Moon, just as the Moon already always keeps the same face turned toward the Earth.