The air parcel concept and the dry adiabatic process

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The air parcel concept

The *air parcel* is an important and useful conceptual device in atmospheric sciences. We make a parcel by gathering together a usually unspecified amount of air and pretend the air is surrounded by an invisible boundary that insulates the parcel air from its surrounding environment. The parcel boundary, however, is flexible, permitting the air inside to expand or contract as conditions dictate.

The flexibility of the boundary implies that outside and inside pressures will always be the same... and thus if the outside pressure drops for some reason, so too will the inside pressure. In that event, the parcel will expand. Similarly, an increase in outside pressure will cause the inside pressure to rise accordingly, making the parcel contract. One very good way of making a parcel's outside pressure to rise or fall is to make the parcel sink or rise in elevation. This is very important. We will eventually see there are other ways of making the pressure change as well.

Now consider such an air parcel, consisting of only *dry air* for now (we'll be adding moisture soon). Our four principal air parcel assumptions are:

1. The parcel is **sealed** from outside air. Thus, there is no mixing of parcel and environmental air once the parcel is created. For a dry air parcel, the mass is fixed.
2. Parcel size itself is irrelevant.
3. The parcel is **insulated** from its surrounding environment. Thus, there is no heat transfer by conduction or radiation across a parcel boundary.
4. The parcel sides are **flexible**, which means if outside pressure changes, inside pressure adjusts to match it.

These assumptions may seem ridiculous, but we will show that they're actually pretty good for the parcel concept applications we're going to consider. Note the fourth point means that a balloon is not a good proxy for an air parcel; the outside and inside pressures are clearly different in that case.

Recall the ideal gas law (IGL) here: *since the parcel and environmental pressures are always the same, if the parcel is warmer than the environment, it is also less dense*. Thus, if the parcel temperature exceeds that of its surrounding environment, the parcel will want to rise. Similarly, if we find a parcel to be cooler than its surroundings, it will be more dense, and therefore will want to sink.

The important point to keep in mind is this:

For a dry air parcel, the only way to change its temperature is to change its pressure.

A non-intuitive example

Suppose it's a hot day and the outside temperature and pressure are 90°F and 1000 mb, respectively. The air is perfectly dry; vapor supply is zero. You make a parcel from this air and bring it indoors, where p is also 1000 mb and the air conditioner is operating. The parcel's new environment is 70°F but your parcel is still 90°F, because you did not change the pressure. Next, you put your parcel in your freezer, where the temperature is 0°F but the pressure is still 1000 mb. What's the parcel's temperature? 90°F.

This seems absurd. How can such an assumption be useful?

If you leave something, whether it's an air parcel or a can of soda, in the freezer long enough, it will become very cold – it will cool down to the temperature of the freezer. However, that takes time. If you put a soda can in the freezer for only a few minutes, its temperature will not change very much. That time span is too short. **We are presuming short life spans for our air parcels.** A deep cumulus cloud can carry an air parcel from your toes to the tropopause in about 15 minutes. In that time span, the assumption that the temperature inside a dry air parcel only changes owing to pressure changes outside is a pretty good one.

Definition of lapse rate

A **lapse rate**, specified as °C/km or °F/mi, quantifies how quickly temperature changes with height under specified conditions. The word *lapse* implies our expectation that temperature will decrease with increasing elevation. If the temperature were to increase with height, the lapse rate would be negative.

The dry adiabatic lapse rate (DALR)

Suppose you are heating water to make pasta. You are adding heat to the water. That process is called *diabatic*, which comes from the Greek word for "passable, possible, to cross over or through". What is crossing over or through is the energy being used to heat the water.

The opposite of diabatic is *adiabatic*, Greek for "impassible, impossible". An adiabatic process changes the temperature of an air parcel without addition of heat energy from outside the system or extraction of heat energy from the parcel. As far as heat exchange is concerned, the parcel boundaries are impassible. For a dry air parcel, however, you can change its internal temperature by expansion or compression. This is called the **dry adiabatic process**, because the air is dry and the temperature change does not involve heat exchange with the environment.

Now, let's take an insulated yet flexible air parcel composed of surface air and we make it rise. We are still assuming there is absolutely no moisture in the air. As that parcel rises, the pressure outside of the parcel decreases. Because the parcel boundary is flexible, the inside pressure also goes down. This permits the parcel volume to expand. Expanding air cools, so the T inside the parcel is dropping. The rate of expansion cooling for dry air is very close to 10°C/km or 30°F/mi and is called the **dry adiabatic lapse rate (DALR)**. More exact values are 9.8°C/km or 29°F/mi, but we will often round them for convenience. The DALR is positive because temperature decreases (e.g., lapses) with increasing elevation.

Using air parcel assumptions, lifting an air parcel results in a very fast rate of cooling. Lift a parcel 1 km, it becomes 10°C colder. Lift it one mile, it becomes 30°F colder. All because air is compressible and pressure decreases with height. No heat was exchanged with the environment. The parcel got colder because it got bigger and it got bigger because the pressure acting on the flexible parcel from outside decreased.

By the same token, forcing air to sink results in a very fast rate of warming, not because we are adding heat to it but because of compression. Push the parcel down 1 km, it becomes 10°C warmer. Push it down one mile, it becomes 30°F warmer. All because air is compressible and the parcel's surrounding pressure increased. No heat was exchanged with the environment to make the air hotter. The parcel got warmer because it got smaller and it got smaller because the pressure acting on the flexible parcel from outside increased.

By far the easiest and quickest way to change the temperature of air is to change its altitude. That's interesting. But soon we have to also take moisture into account as well. That's more complicated, but even more interesting. If an insulated parcel contains water vapor, but is and remains substaurated, the dry adiabatic process still applies, at least until saturation is achieved and the condensation starts. We can also call the dry adiabatic process as the **subsaturated adiabatic** process.