Reversible and ideal

Reversibility

A reversible process is one that *could* be done in the reverse order so that *both* the system of interest and the rest of the universe with which it interacts are returned to their original states. Note the emphasis. It is reversible if the steps could be reversed as described, it is not necessary that they actually are reversed. Also it is always possible to return just the system to its original state. So the condition that it is both the system and its environment that are returned to their original states is crucial to giving the statement meaning.

Examples: A Carnot cycle is reversible. Indeed each of the four steps of a Carnot cycle are reversible. Heat flows by thermal interaction between systems with a finite temperature are irreversible. Energy dissipation due to friction is irreversible. The free expansion of a gas is irreversible.

In any real system there is some imperfection like a little friction that prevents it from being perfectly reversible. So there no real Carnot engine that is perfectly reversible. On the other hand, one can reduce the friction to insignificant levels and get a real Carnot engine that is a very good approximation to reversible.

For a free expansion the situation is different. A free expansion is not an approximation to some reversible process. The irreversibility in a free expansion is intrinsic to what we mean by free expansion. For example, making the free expansion slower by making the hole the gas escapes through smaller does not make the process any less irreversible.

Thus we might say that there are two kinds of irreversibility. Let me call them essential irreversibility and inessential irreversibility. (You will not find these names in books. I am just making them up now for the purpose of this discussion.) The irreversibility in a free expansion is essential. It is implied in the definition of the process. The “idea” of a reversible free expansion is a contradiction.

The irreversibility of a real Carnot engine is inessential. It is not contained in the definition of a Carnot cycle. We can make a real Carnot engine better and better and make the irreversibility smaller and smaller. We can then imagine the limit of a perfect Carnot engine that has no friction and is exactly reversible. This brings us to the notion of ideal.

But first: Although we can draw this distinction between essential and inessential irreversibility, there is no implication that there is a different *physical mechanism* at work. The physical mechanisms in friction and free expansion are, from the perspective of statistical mechanics, very similar. They are both associated with increasing randomness on the atomic scale.

Ideal

The meaning of ideal is somewhat context dependent. In this context, probably the best thing to say that an ideal engine or process is one in which the *inessential* sources of irreversibility have been eliminated. Thus an ideal Carnot engine has no friction and is perfectly reversible. So while it may not be possible to build a real ideal Carnot engine, it is possible to get closer and closer to the ideal until one has a very good approximation to it.