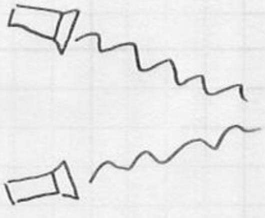
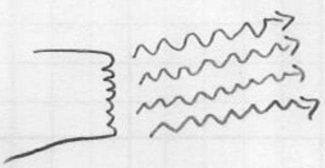
Introduction to coherence.

Interference sounds like such a simple phenomenon. If you have more than one source of light, the net field comes from adding the individual fields everywhere, and sometimes they reinforce one another, and other times they cancel out.

So why don't we see interference all over the place, like every time we shine two flashlight beams together? That's where the notion of coherence comes into play



Two flashlights that made pure sine waves would absolutely interfere. But flashlights don't make sine waves. Or pure spherical waves. And I don't just mean the fact that they're not monochromatic.

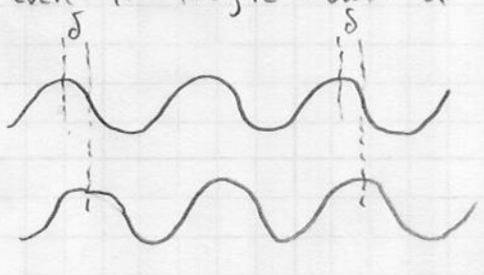


A flashlight beam comes from a filament, which isn't a point source. It's many individual point sources, many atoms, none of which are reliably in phase or out of phase with one another, so it all kind of washes out into a big blur.

This is spatially incoherent light: light such that the fields in one location are uncorrelated with bits in another location.

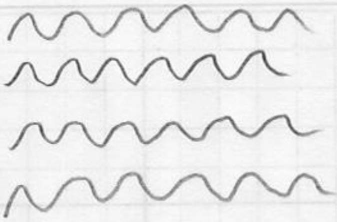
Note that for two things to be correlated, knowledge about one needs to give you knowledge about the other.

Two pure sine waves, for example, are perfectly correlated, even if they're out of phase



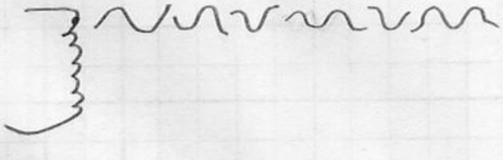
If you know you have two sine waves out of phase by δ, then knowing the field from one at a certain point also lets you figure out the field of the other.

And strongly correlated light will show interference. As you vary that phase angle δ, the net result will go from bright to dark and back to bright.

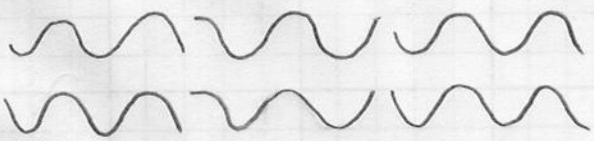


But if you have a bunch of sine waves with all sorts of phase relationships, knowing what one is doing doesn't tell you much about what the others are doing. And if you start varying the phase relationships, the net field doesn't change — uncorrelated (incoherent) light doesn't exhibit interference.

There's also something called temporal coherence. Consider that flashlight filament again, but only one single atom. Even that one atom doesn't produce a pure sine wave either. It's hot and bothered and is getting jostled around and photons it emits now are generally uncorrelated with photons it emits later



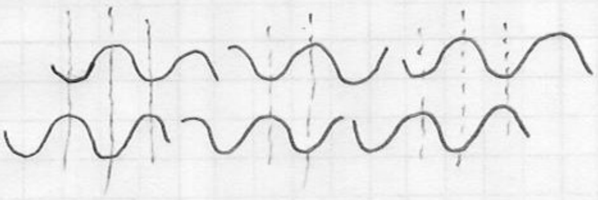
So the emitted wave looks like that. That's <u>temporally incoherent</u> light. But not perfectly incoherent — so let's make things just a bit more quantitative.



So let's take a sine wave that has phase jumps from time to time, split it into two identical waves, and see what they do

If there's no relative phase between them, they interfere constructively at every point along their length.

So now let's slide one over by half a wavelength:



In most places, you get peaks adding to peaks and troughs adding to troughs, so the waves <u>mostly</u> destructively interfere.

But near the discontinuities, there are places where that doesn't quite happen, so the destructive interference isn't total.

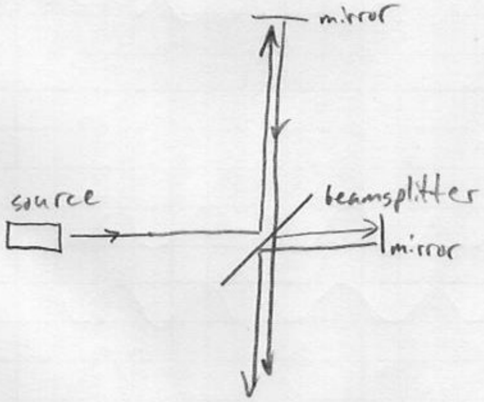
And if you slide them way out of phase, you get to where any two points on the waves are just as likely to add up constructively as destructively, so the average over the whole length isn't either one - it's just some middling half-bright - Kind of like what you get when you combine two actual flashlight beams.

That means there's some kind of characteristic time and length scales here: a coherence time τ_c and a coherence length l_c.

If some light is experiencing phase resets roughly every τ seconds, τ_c is roughly τ, and l_c is roughly $c\tau$ (or $v\tau$ if the wavespeed isn't c).

If you combine sources with coherence length l_c and they're within l_c of being in perfect synch with one another, you'll get some noticeable interference. As you slide the one with respect to the other, you'll get alternating bright and dark. But as they get out of synch by more than l_c, the interference will fade away.

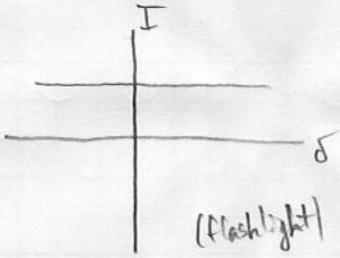
Consider a nice, normal Michelson interferometer.



You take a single source, split it in two, and recombine the halves after letting them travel possibly-different distances.

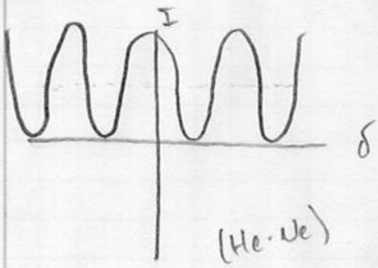
By controlling those distances you can induce constructive or destructive interference... if your light is sufficiently coherent. "Sufficiently" meaning that the path length difference is less than the coherence length.

If you feed a flashlight beam into a Michelson interferometer, the coherence length is essentially zero and the output intensity vs. relative phase angle will be flat:



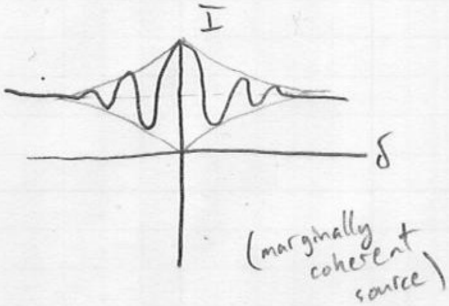
(flashlight)

But if you take a source with a long coherence length (like a He-Ne laser and feed in into the same system, you'll get:



(He-Ne)

And if you use something like a diode laser that has a short but not totally negligible coherence length, you might get something like:



Fun fact: Holograms involve recording interference patterns onto high-res film, and as such require a coherent light source (no coherence: no interference). And since highly coherent light usually comes from highly monochromatic lasers, the most straightforward true holograms are generally single-color.