# Detailed statement on faster-than-*c* light pulse propagation

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We summarize the relevant details of our new findings reported in our paper to appear in the July 20, 2000 issue of Nature as follows.

1) **Repeatability:** The experimental study has been performed with great care and repeated numerous times. The results are consistent with what our theoretical model predicted. The theoretical model is entirely based on existing physics theories of Electromagnetism and Quantum mechanics.

2) **Earlier press coverage:** It has been mistakenly reported that we have observed a light pulse's velocity exceeding *c* by a factor of 300. This is erroneous. In the experiment, the light pulse emerges on the far side of the atomic cell sooner than if it had traveled through the same thickness in vacuum by a *time* difference that is 310 folds of the vacuum transit time. Vacuum transit time is the time for light to traverse a distance in vacuum (in our case, the distance is 6 cm and the vacuum transit time is hence 0.2 nanosecond).

   In our experiment, a smooth light pulse of about 3-microsecond duration propagates through a specially prepared cesium atomic chamber of 6-cm length. It takes 0.2 nanosecond for a light pulse to traverse a 6-cm length in vacuum. In our experiment, we measured that the light pulse traversing through the specially prepared atomic cell emerges 62 nanosecond sooner than if it propagates through the same thickness in vacuum. In other words, the net effect can be viewed as follows: the time it takes a light pulse to traverse through the specially prepared atomic medium is a *negative* one. This negative delay, or a pulse advance, is 310 times the "vacuum transit time" (time it takes light to traverse the 6-cm length in vacuum).

3) **Einstein's Relativity:** Our experiment is *not* at odds with Einstein's special relativity. The experiment can be well explained using existing physics theories that are consistent with Relativity. In fact, the experiment was designed based on calculations using existing physics theories.

   However, our experiment does show that the generally held misconception *"nothing can move faster than the speed of light"* is wrong. The statement only applies to objects with a rest mass. Light can be viewed as waves and has no mass. Therefore, it is not limited by its speed inside a vacuum.

Information coded using a light pulse cannot be transmitted faster than *c* using this effect. Hence, it is still true to say that *"Information carried by a light pulse cannot be transmitted faster than c."* The detailed reasons are very complex and are still under debate. However, using this effect, one might be able to increase information transfer speed up to *c*. In present day technology, information is transmitted at speeds far slower than *c* in most cases such as through the internet and inside a computer.

*4)* **Interpretation:** *No* intuitive way to explain this observed effect *precisely* can be found because the "specially prepared" atomic cell is in a state that *does not exist naturally*. Human intuition is based on our observing daily occurring events. The phenomenon we recently measured does not occur naturally, let alone in daily life. The only other condition to measure a similar effect in *nature* is inside an opaque material that does not transmit light. Obviously, inside an opaque (non-transparent) material, although a similar effect exists, it is not visible (non-transparent) and hence not intuitive. These superluminal effects have long been properly named as "*Anomalous Dispersion."* They are anomalies to our daily experiences.

***However*,** the effect can be understood in a less precise way as follows:

Suppose we take a "snapshot" of the propagation of a light pulse at a certain time, the picture will generally look like that shown in Figure 1. *(Precisely speaking, one cannot take a picture of light itself. The effect in Figure 1 is further greatly exaggerated for the purpose of illustration.)*

A light pulse is made of many wave components of different wavelength (frequency). Here we show three of these components (waves 1 to 3). First in air, all three waves are in phase in region-1 where the waves add to produce a pulse. Slightly further in space along its propagation direction, the waves become "out of phase" and the waves cancel each other.

In an anomalous dispersion region (Region-2 inside the Cesium atomic cell), a wave which has shorter wavelength in vacuum (wave-1) now has a longer wavelength. Conversely, a shorter wavelength wave (wave-3) becomes a longer wavelength wave. Hence the waves' phase are accordingly modified. When the three waves emerge again from the Cesium cell's exit surface, they restore their wavelengths. Due to the unusual phase modulation of the anomalous dispersion material, the three waves are in phase again in a third region (Region-3 in air). In this region, the three waves again add to produce the exact form of the incoming pulse.

Ordinarily in air and as a matter of fact in all *normal dispersion* materials, a light pulse cannot re-phase to appear at a distant place along its propagation direction. Normally, the light pulse will appear at such a distant place along its propagation at a later time. However, owing to the extraordinary properties of an *anomalous dispersion* material, a light pulse can ***rephase*** to appear at such a distant place along its propagation direction. Thus the light pulse behaves as if it takes a negative time to traverse the distance in between. This effect is due to **rephasing.**

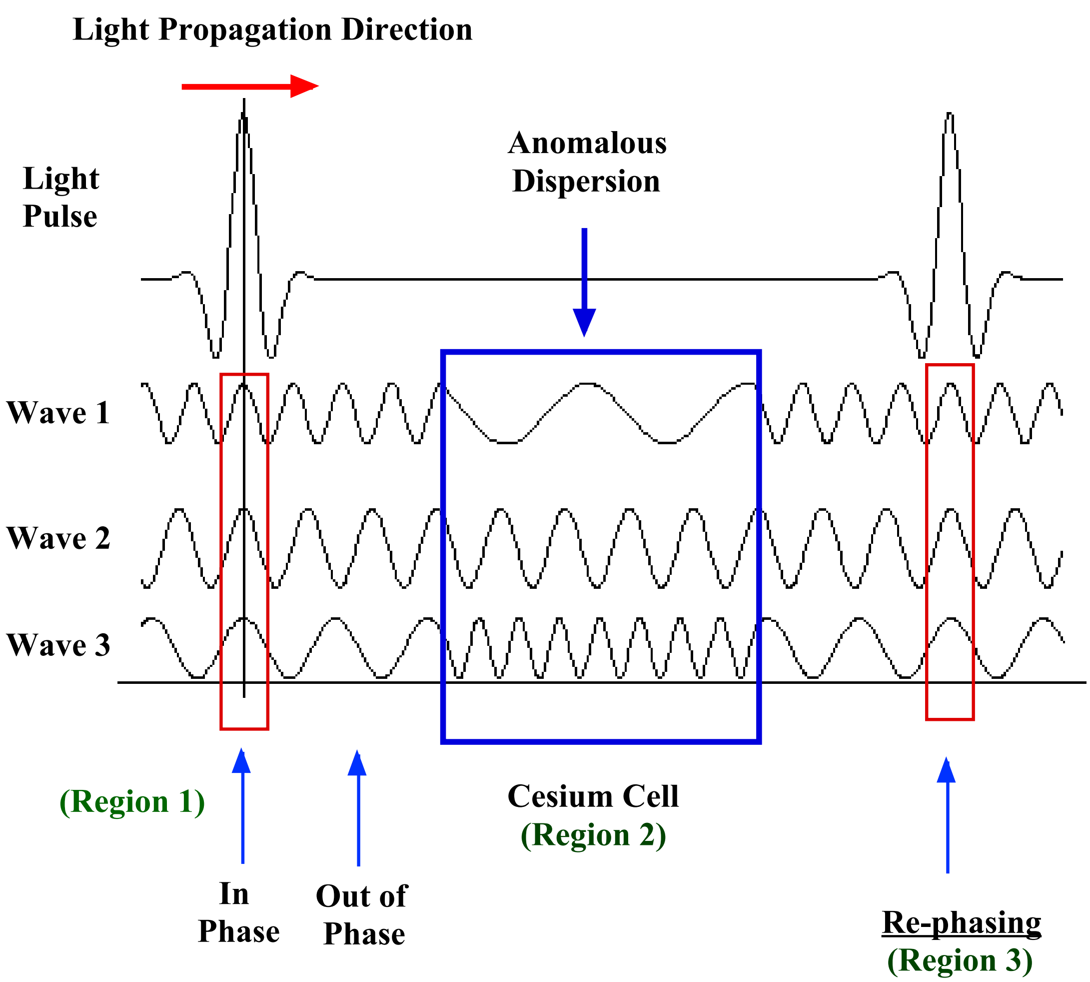
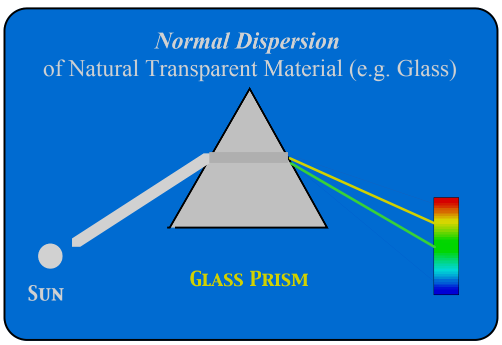
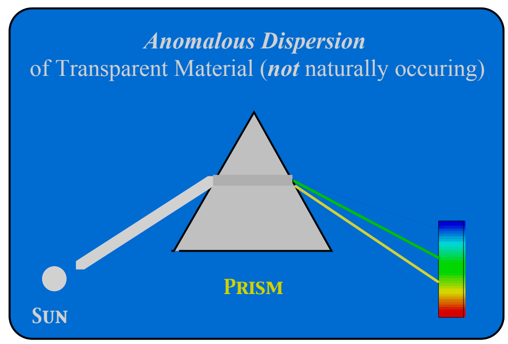



**Figure 1. A "snapshot" of a propagating light pulse. A light pulse is made of many component waves (waves 1 through 3). Inside an anomalous dispersion region (region-2), the waves propagate in an unusual way. The result is that the waves are "rephased" again at a distant place along its propagation direction to produce the incoming pulse. The effect is greatly exaggerated here for the purpose of illustration.**

As an example to illustrate dispersion, let us consider the case of sunlight incident onto a triangular glass prism (Figure 2a). Coming out of the other side of the prism we see a spectrum of rainbow colors. Observing carefully, one will see that red light in the sunlight is bent less than blue light as shown in Figure 2a. This effect holds true for all naturally occurring transparent materials and is called *“Normal Dispersion.”* If one were to make a prism using materials with properties similar to the specially prepared Cesium gas in our experiment (Figure 2b), the order of its output spectrum will be reversed. In other words, red light will be bent more than blue light. A case like this will correspond to *“Anomalous Dispersion.”* However, such a dispersion property does not exist for transparent materials in the natural world.




**(a) Normal Dispersion**




**(b) Anomalous Dispersion**

**Figure 2. (a) Dispersion of sun rays by a glass prism *(normal dispersion)*. (b) Reverse order of spectrum for a prism made of an *anomalous dispersion* material. In the natural world, such a transparent *anomalous dispersion* material does not exist.**

In a normal dispersion material, a light pulse travels slower than its vacuum speed *c*. By contrast, in an anomalous dispersion material, a light pulse can travel faster than *c* as is demonstrated in our experiment.

5) **Novelty:** The specially prepared Cesium atomic gas is not naturally occurring. Specifically, natural Cesium can exist in 16 possible quantum mechanical states. These quantum mechanical states are called “hyperfine ground state magnetic sub-levels.” In our experiment, we drove almost all cesium atoms to only one of the 16 possible quantum mechanical states, which corresponds to an almost absolutely zero degree in temperature in the Kelvin scale (-273.15 degree C and obviously not

naturally occurring on earth). This is achieved via a technique named “optical pumping” using lasers. It is worth noting here that a laser itself is not a naturally occurring phenomenon either. A laser has properties that are very closely related to the atomic medium used in our experiment.

6) **Applications:** It is our hope that our work can find its usefulness in peaceful applications that benefit humanity.