ECE 5/6358 HW 1 (150 pts)

First name, Last name

Student ID:

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Below are excerpted works from HW 1 of two individuals from the class. Many have have very good answers also, and over the semester, we will take turn to cite the works of others. This time, two people's works are selected as A and B below, highlighted in light blue. Instructor's comments are in light green. However, there are some mistakes and errors that many in the also class did (including selected works). These are high-lighted in light red.

1.(50 pts) Interest in optics or optoelectronics

Write ~ 0.5-1 page (figures & references included) on a topic in contemporary optics/photonics science and technology that interests you, or you are curious about (*a reason you take this course*).

2.(50 pts) Periodic phenomena

Consider three physical phenomena:
- phenomenon ***a***: periodic in time: $u = \text{Cos}[2\,\pi\,f\,t]$ (u is just a variable representing amplitude)
- phenomenon ***b***: periodic in space: $v = \text{Cos}[k\,x]$
- phenomenon ***c***: periodic in both space and time: $q = \text{Cos}[k\,x - 2\,\pi\,f\,t]$

Below is the code that calculates and plots the three phenomena. You don't have to do anything but executing the code, vary various parameters, and observe. Write all you think you learn about the phenomena, especially "***c***". Remember: to see a time phenomenon, run variable time; to see a space-periodic phenomenon, sample (measure) over a range of space; and do both time and space for "***c***"

- *Code for calculation (no need to see, just Shift+ENTER to execute - delete the output - NOT THE CODE - after done)*

Example A

Answer : A - when varying the time with not changing frequency nothing happened because the first one is a function depending in frequency and time.The frequency needed to be changed to some value and then varying time **we could see that both a and c were moving** because they
are dependant on time.

However, b showed no change because it is a function of space and does not
depend on time.B - when we varied the value of x (space) with k set to some value we
noticed **a movement in b & c** because they are both dependent on space
and change value if x change.A showed no movement (because it is only dependent of time).

In case of c we noticed that **no matter which variable we are varying it is always moving whether it was space or time it is in a constant movement** and that is why it is differnet from the two functions it is always propagating (through time and space)

Instructor's comment: The error here is that **a has no movement.** Let's plot the temperature of Houston over time. We will see that the temperature varies as a function of time, but does temperature "moves" like people move around the city? No. We plot the temperature and it moves up and down ONLY in the graph. It has NO real physical movement. So, it is just semantic. In science, we have to be very careful of every word we use.

Example B

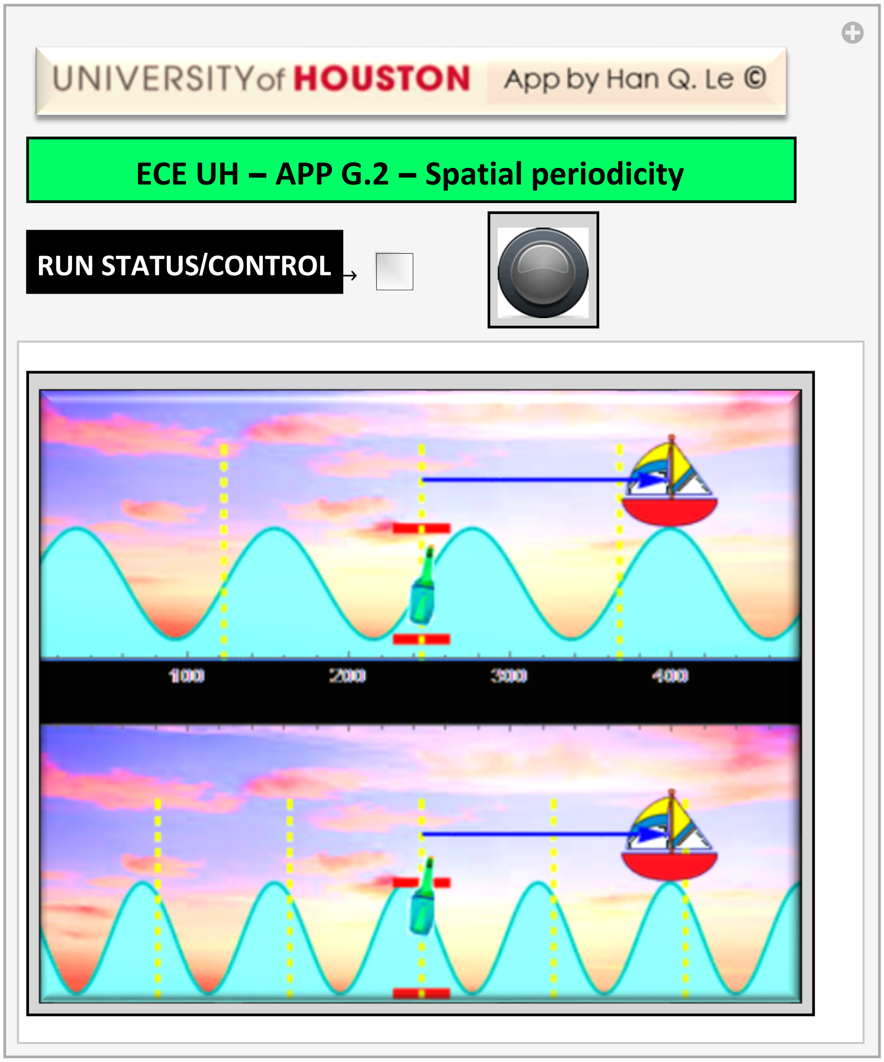
2.

Phenomenon A shows a point oscillating in time varying from 1 to -1 with the frequency controlled by the variable f. Variable k controls the frequency of the waveforms in B and C. Adjusting xmax changes how far out into "space" phenomena B and C extend. Phenomenon C shows a wave oscillating in space with the phase controlled by the time domain oscillations. Adjusting the frequency f and the time t moves the waveform in C in and out of phase with the waveform in B. In waveform C, the frequency is controlled by the kx term, and the phase is controlled by the -2πft term. Waveform A moves with time, Waveform B is static in space, and Waveform C propagates through space because it changes with time.

Instructor's comment:

The essence of science is observation, looking for clues, and interpretation. Seeing with a critical eye and not seeing with what your preconceived notion in the brain tells you. Example B is excellent on the last sentence except for a nomenclature error: A and B are NOT waveform. Only C is qualified as "waveform". This appears to be a semantic issue, as author B might use "waveform" as just a word for "entity, quantity, or phenomenon, or even mathematical function". In physics, do not confuse a function with "waveform". Wave has a unique and specific meaning, and this course is about EM waves in the frequency range of 10^{14} Hz (100's of THz).

App that maybe helpful to HW - use to gain concepts and understanding to do Problem 3 (*this is NOT a problem of the HW*)



3.(50 pts+10 pts bonus) Frequency and wavelength

- We have a group of students who pick 3 wavelengths: 0.65 μm (red DVD laser), 0.532 μm (green laser pointer), 0.405 μm (BluRay laser) (a wavelength, if not specified, is always meant to be in vacuum).
- We have another group of students who pick 2 frequencies: 527 THz and 384 THz. (1 THz = 10^{12} Hz),

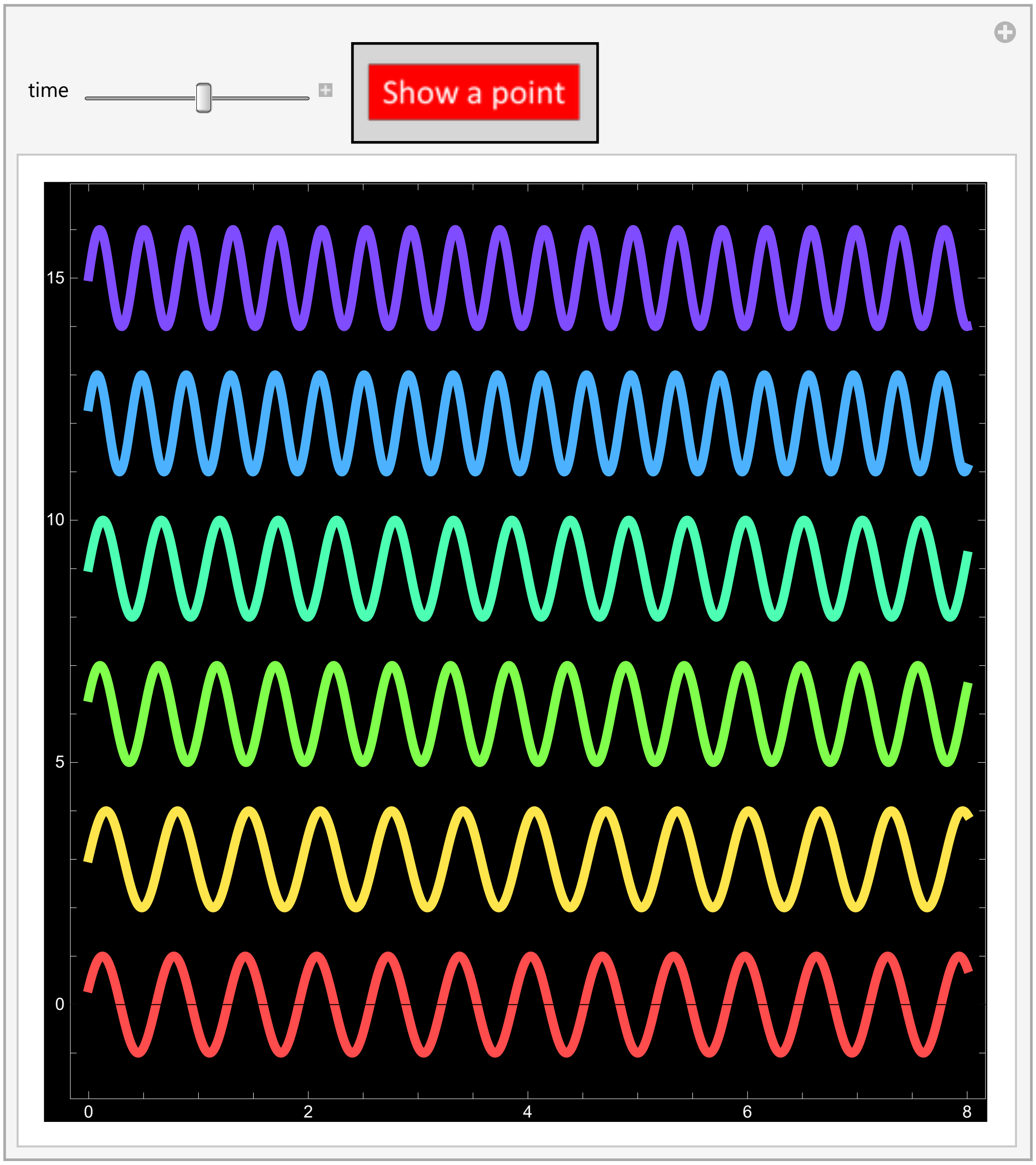
Each question below is worth 10 pts - **Answer thoroughly and thoughtfully**.

3.1 Hypothetical waves

If we could (**hypothetically**) make waves that could be from all arbitrary combinations of wavelengths and frequencies, how many waves can we make and what do they look like when traveling. Just run the code and discuss **the single most significant observation**. (if someone tells you that you can say ONLY ONE thing that you notice about the waves below, if it is correct, you will get $1M, and incorrect, $0. Only one. If you make more than one point, you will get zero. What would you say?).

- *Code (no need to see, just Shift+ENTER to execute - delete the output - NOT THE CODE - after done)*

Out[ ]=



Example A

Answer:
Hypothetically speaking if we could create 6 waves depending in the given input frequencies and wavelengths they will be combined as follows:
{(0.65, 527), (0.65,384), (0.532,527), (0.532,384), (0.405,527), (0.405,384)}
Then their speed would be calculated by multiplying the frequency by the wavelength for each one.
We notice when we run the code that we get 6 waves traveling at different speeds.

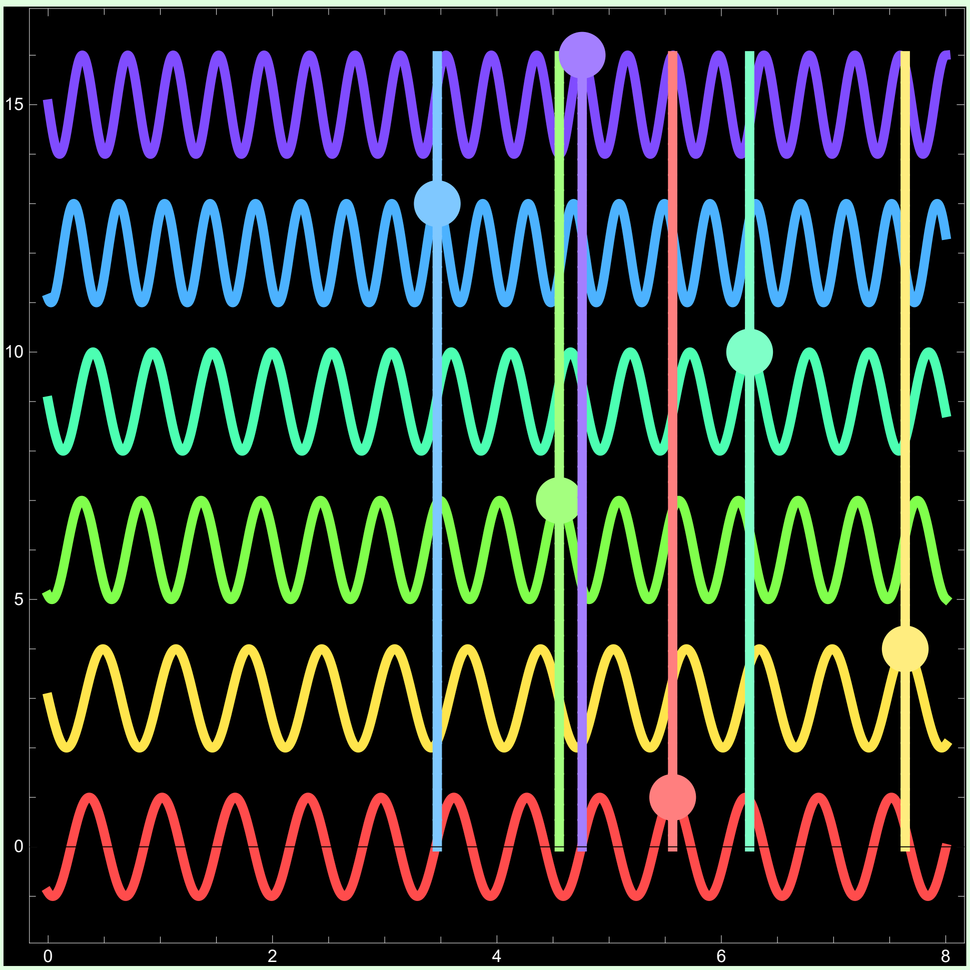
The one thing I could say about the waves that they have different propagation velocity.

Example B

3.1 – We would be able to make 6 different waves. The single most significant observation is the propagation speed of each wave.

Instructor’s comment:

Watching the movement, with the location of the point on each wave vs. time, can’t one tell what is the most obvious? **Science is about observation**. The most obvious thing here is that the fixed points on the waves move at different speeds.



3.2 Identify the waves

All the 6 waves you see above have the form: Cos[$k\,x - \omega\,t$] where k is $\frac{2\pi}{\lambda}$ and ω is $2\,\pi$ f. Denote them from 1 (top) to 6 (bottom), Can you match each wave with its λ and f? For example:

wave 1 corresponds to {0.532 μm, 384 THz} (incorrect, but just an example)

Example A (same as above because it explains both)

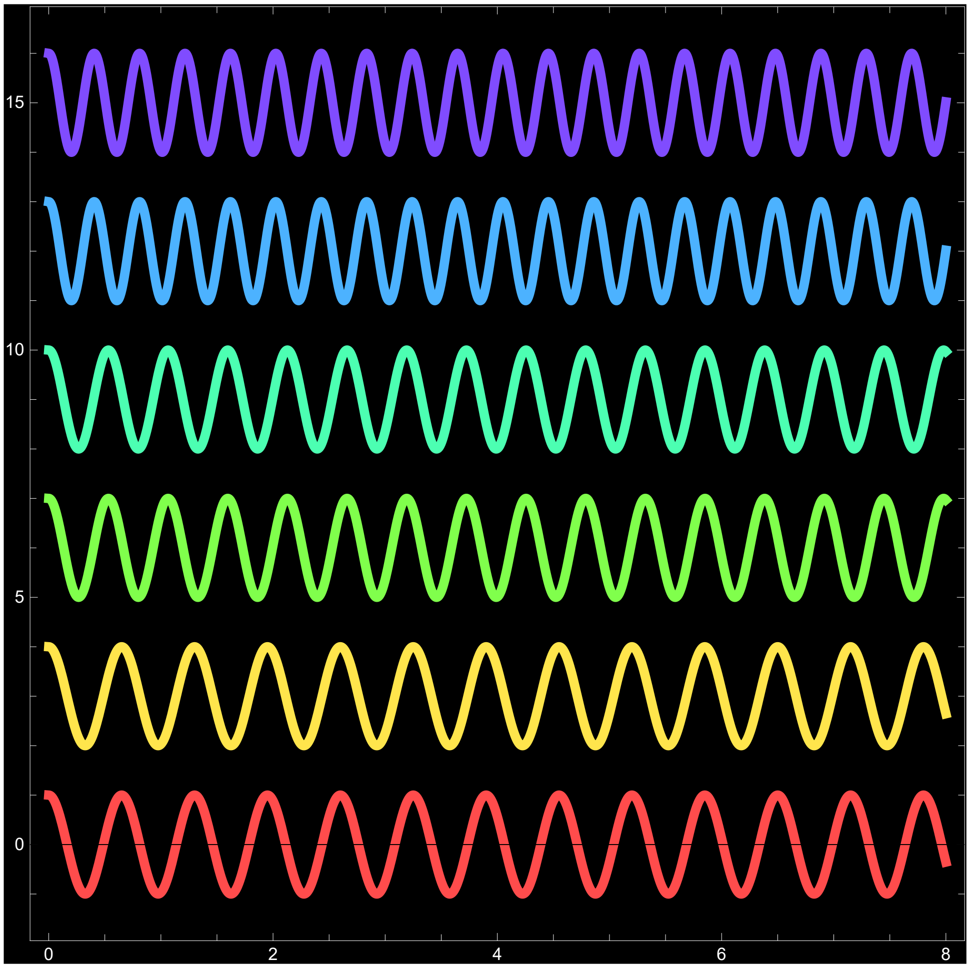
Example B

3.2 – Yes, we can match each wave with its corresponding λ and f
Waveform 1 – Purple – {0.405μm, 527THz}
Waveform 2 - Blue – {0.405μm, 384THz}
Waveform 3 - Blue/Green – {0.532μm, 527THz}
Waveform 4 - Green – {0.532μm, 384THz}
Waveform 5 - Yellow – {0.650μm, 527THz}
Waveform 6 - Red – {0.650μm, 384THz}

Instructor’s comment:

Example B is perfect. Example A is correct, but it did not specify the order (bottom to top or top to bottm). Here, for the time being, it is given the benefit of the doubt just like many other works in the class that also give a correct list without a clarity of the order.

Science is about observation. What is wavelength? what is the **operational meaning** of it? If one sees it, does one recognize what it is? Look at the chart below, what does one automatically recognize about the wave-length? They come in pairs, top two have the same wavelength, then the next two, and the last two. Which wavelength is the shortest? (smallest), which one is next? etc... As we know the wavelengths are: “ *0.65 μm (red DVD laser), 0.532 μm (green laser pointer), 0.405 μm (BluRay laser)”* It’s obvious that the top ones are 0.405, then 0.532, and the bottoms: 0.65/



OK. We identify them into 3 groups by wavelength, but what about within each group? If we animate and even just look at one location such as x=0, it is obvious that within each pair, the top one **oscillates faster** than the bottom one, which means it has **higher frequency**. This tests the **operational understanding** of “frequency”, which is the rate of oscillation: the number of cycles per unit time.
Thus, it is straight forward to identify the wave: by **operationally looking** at its wavelength and frequency.

What does “**operational knowledge**” mean? Here is an example: John and Bob walk along the seaside of a town. Suddenly, there is a siren of “tsunami” warning. John has the academic knowledge of “tsunami”. He knows that tsunami comes from Japanese word for “harbor wave”, which is a big wave of water that moves in from the sea. John thinks he wants to stay to watch it. Bob however, immediately runs for his life. Bob is said to have an “**operational knowledge**” of tsunami. John is said to have a “**wiki** or **Internet knowledge**” of tsunami.

In the above, if a person **recognizes that the spatial periodicity of the top plot is shorter than the lower ones, hence it must correspond to shorter wavelength**, then the person is said to have an “**operational knowledge” of wavelength**. Likewise, if the person knows **faster oscillation means higher frequency**, that’s an **operational knowledge of frequency**.

3.3 Speed

We learn that the wavespeed is $\frac{\lambda}{T} = \lambda f$ (See the app above again about the wave speed not sure).

Below is the calculation of the 6 wave speeds. The unit is μm/ps.

In[∘]:=
```
Grid[Join[{{"λ", "f", "speed"}},
  ReverseSortBy[Flatten[Table[{v, u, u * v}, {u, f}, {v, λ}], 1], Last]] ,
 BaseStyle → {24, FontFamily → "Calibri"}, Frame → All,
 Background → {{, ,}, {Hue[0.3, 0.4, 1], , , , , ,}}]
```

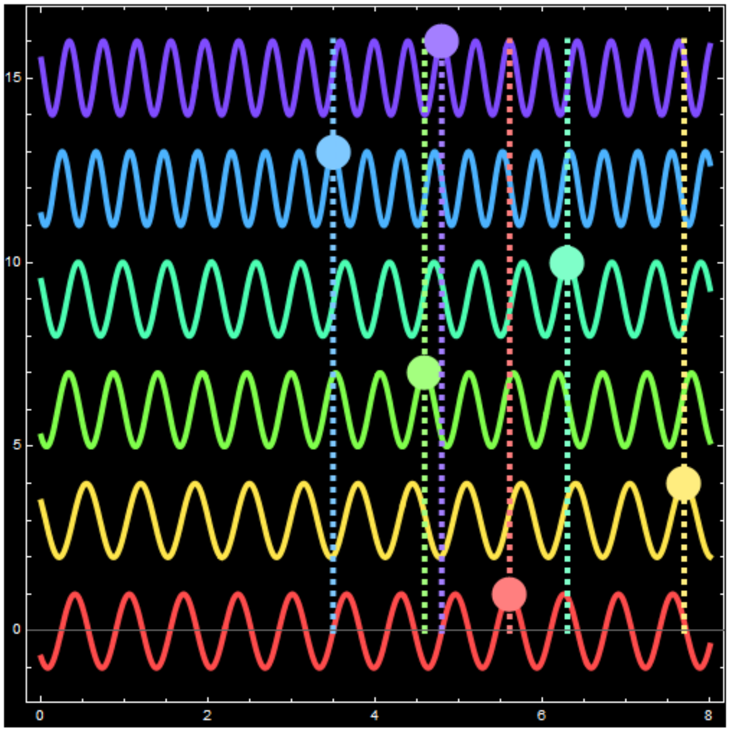
Out[∘]=

λ	f	speed
0.65	527.	342.55
0.532	527.	280.36
0.65	384.	249.6
0.405	527.	213.44
0.532	384.	204.29
0.405	384.	155.52

Watch the waves in 3.1 again, Can you tell which wave with what wavelength and frequency just by watching? What is the principle behind the approach that you use to identify each wave?

Example A

Answer:
Based on the observation from question 3.1 and the calculated velocity in 3.2 the waves can be easily defined if we show point and notice which ones are the fastest and which are the slowest.



we can see based on the point shown on each wave that the yellow one in the fastest with speed (342.55) and the light blue one

3.4 Given that propagation is such a fundamental property, the speed must be a constant of nature (otherwise nature would be a mess)

The speed of light is 299.792458 μm/ps in vacuum, independent of frequency (in 1 ps, light travels about 1/3 of a millimeter, or ~ 6-10 times the width of our hair). Can you calculate the correct frequencies for the 3 wavelengths above and watch how each wave propagates? You only have to calculate f, The code for the wave propagation is given, what is the single most significant feature in the way the waves propagate?

- *Code (no need to see, just Shift+ENTER to execute - delete the output - NOT THE CODE - after done)*

Example A

Answer :
The wave speed = the wave length * the wave frequency
The wave speed = c (the speed of light)
The fwavelengths = { .65, .405, .532}
The wave frequency = the wave speed / the wavelegth
f1 = c/λ
= 299.792458*10^6 / 0.65*10^-6
f1 = 461.219 THz.
the same equation applies to f2 & f3

the outputs :
f2 = 740.228 THz
f3 = 563.519 THz
the frequencies are { 461.219, 740.228, 563.519} for wavelengths = {0.65, 0.405, 0.532} respectively.
cl = 299.79

3.5 Speed of light measurement

If you look up any physical quantity, such as those listed on this NIST website:
https://physics.nist.gov/cgi-bin/cuu/Category?view=html&Frequently+used+constants.x=69&Frequently+used+-constants.y=29

almost every quantity has some experimental uncertainty. For the speed of light however, it is exactly 299.792458 μm/ps. No error. Why is that?

Example A

Answer:
It is one of the fundamental concepts of the universe we live in.
The second is the Standard International (SI) unit of time. One second is the time that elapses during 9,192,631,770 (9.192631770 x 10 9) cycles of the radiation produced by the transition between two levels of the cesium 133 atoms. Therefore, the second is an absolute reference with no uncertainty, and we measure other stuff using the physical definition of a second as a reference point. The speed of light measures the distance the light travels per second. The speed of light units of measurement is (m/s). In physics, any number that has units attached to it can have any value that it wants.
To express the speed of light (m/s), one must first define what a meter is and what a second is. Hence, the speed of light definition is related to the definition of length and time.
Most physics matters are constants that do not have units of measurements (constants that appear as simple numbers). One of these numbers is the fine structure constant, which is a combination of the speed of light, the Planck's constant, and something known as the permittivity of free space. It has a value of about 0.007. Technically, the speed of light can be whatever we want because it contains units, and we need to define those units. On the other hand, the speed of light can only be precisely what it is, because if we were to change the speed of light, we would change the fine structure constant, but the universe in which we live has chosen the fine structure constant to be about 0.007, not another number. Therefore, the speed of light is constant and has no value of uncertainty.
It is a fundamental concept of the universe we live in.

Example B

3.5 – The speed of light has no experimental uncertainty because a meter is defined as the length of the path travelled by light in a vacuum during a time interval of 1/c seconds. A second is a universally agreed upon constant defined as the duration of 9,192,631,770 periods of the radiation corresponding between two levels of the ground state of the caesium-133 atom. Because a second is exact and a meter is defined in terms of light, the speed of light is exact.

3.6 (bonus) Gravitational wave vs light wave speed

On Sept 14, 2015 at ~9:51 UTC, people detected a gravitational wave for the first time. It was a result of two black holes merging. Do an Internet search when that two black holes merged.

it happened a long long time ago in a galaxy far far away.

(1.3 billion light –years)

In the original paper (and on LIGO website), people actually published the experimental uncertainty about the difference between c_L, the speed of light, and c_G, the speed of gravitational wave. Theoretically, they have to be equal for General Relativity to make sense. What is the experimental relative uncertainty of their difference and how was it determined? (read the materials and report).

A good news is that you did look thinner for a moment when the space-compress part of the gravitational wave passed through you (but it stretched you out also for its space-dilation part).

Example A

Answer:
The Generalized Uncertainty Principle. According to that principle the uncertainties of the particle's location and momentum could not be established to arbitrary precision. In the gravitational wave event the GUP dimension parapemeters were constrained. Researchers were able to derive a standard energy-momentum despersion

relation and calculate the difference between the propagatiing speed of gravitions and the speed of light.

The proposed version of GUP by MAngano & Man was:

δxδp≥\:0304h[1+β(p)2]/2

were δx & δp are the uncertanties for position and momentum.

β = β0 l^2/n^2

β0 is called GUP parameter.

The speed of gravition in gravitational wave incident was given by researchers to be:

vg= ∂ω/∂p

= c^2 * p / (c^4 * m^2 +c^2*p^2)

=c √1−(m^2c^4/ωg^2) ≈c(1−mg2^c^4ωg^2)

where ωgand mgare the energy and rest mass of gravitons,respectively.Considering that h=4.136×10−15eV·s and c=3×108m/s,then the difference between the speed of gravitons υgand the speed of light ccan be expressed as:

δv= c- vg = mg^2 c^5/ 2ωg^2

δv= 5.6 * 10^(-12) m/s.

Lack of citation

Example B

3.6 – Abbott et. Al (2017) compared measurements from the Advanced LIGO and Virgo detectors with the gamma-ray burst (GRB) 170817A to determine that difference between the speed of gravity and the speed of light to be between $-3\text{x}10^{-15}$ and $+7\text{x}10^{-16}$ times the speed of light. For all intents and purposes the two speeds are equivalent.

Can be better citation but good enough.

Instructor’s comment

Two things:

1- search for correct sources of information

2- presentation (simplification, description in your own words) and citation.

Here is an example how to condense complex information into layman’s words: When the gravitational wave (GW) was detected, almost simultaneously, a sudden burst of extremely high energy photons (known as γ-ray burst or GRB) was detected coming from the same angular direction of the sky as the GW. Both phenomena are best theoretically accounted for as the effects of two black holes merging. If the GW and GRB were purely coincident that had not had anything to do with each other, the chance would be only 1 out of 20,000,000.

Hence, it is a better hypothesis to surmise that both must have come from the same black hole merging event. If so, the speed can be compared, and the result is that the speed of the GW and that of the gamma-ray, which is the speed of light, differs no more than between -3×10^{-15} and 7×10^{-16} of the speed of light.

The Astrophysical Journal Letters, 848:L13 (27pp), 2017 October 20 https://doi.org/10.3847/2041-8213/a

Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A

LIGO Scientific Collaboration and Virgo Collaboration, *Fermi* Gamma-ray Burst Monitor, and INTEGRAL
(See the end matter for the full list of authors.)

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Abstract

On 2017 August 17, the gravitational-wave event GW170817 was observed by the Advanced LIGO and Virgo detectors, and the gamma-ray burst (GRB) GRB 170817A was observed independently by the *Fermi* Gamma-ray Burst Monitor, and the Anti-Coincidence Shield for the Spectrometer for the *International Gamma-Ray Astrophysics Laboratory*. The probability of the near-simultaneous temporal and spatial observation of GRB 170817A and GW170817 occurring by chance is 5.0×10^{-8}. We therefore confirm binary neutron star mergers as a progenitor of short GRBs. The association of GW170817 and GRB 170817A provides new insight into fundamental physics and the origin of short GRBs. We use the observed time delay of $(+1.74 \pm 0.05)$ s between GRB 170817A and GW170817 to: (i) constrain the difference between the speed of gravity and the speed of light to be between -3×10^{-15} and $+7 \times 10^{-16}$ times the speed of light, (ii) place new bounds on the violation of Lorentz invariance, (iii) present a new test of the equivalence principle by constraining the Shapiro delay between gravitational and electromagnetic radiation. We also use the time delay to constrain the size and bulk Lorentz factor of the region emitting the gamma-rays. GRB 170817A is the closest short GRB with a known distance, but is between 2 and 6 orders of magnitude less energetic than other bursts with measured redshift. A new generation of gamma-ray detectors, and subthreshold searches in existing detectors, will be essential to detect similar short bursts at greater distances. Finally, we predict a joint detection rate for the *Fermi* Gamma-ray Burst Monitor and the Advanced LIGO and Virgo detectors of 0.1–1.4 per year during the 2018–2019 observing run and 0.3–1.7 per year at design sensitivity.

Key words: binaries: close – gamma-ray burst: general – gravitational waves

LSC LIGO Scientific Collaboration VIRGO

GRAVITATIONAL WAVES AND GAMMA-RAYS FROM A BINARY NEUTRON STAR MERGER: GW170817 AND GRB 170817A

The gravitational-wave signal GW170817 was detected on August 17, 2017 by the Advanced LIGO and Virgo observatories. This is the first signal thought to be due to the merger of two neutron stars. Only 1.7 seconds after the gravitational-wave signal was detected, the Fermi Gamma-ray Burst Monitor (GBM) and the Anticoincidence Shield for the SPectrometer for the INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL SPI-ACS) detected a short gamma-ray burst GRB 170817A. For decades astronomers suspected that short gamma-ray bursts were produced by the merger of two neutron stars or a neutron star and a black hole. The combination of GW170817 and GRB 170817A provides the first direct evidence that colliding neutron stars can indeed produce short gamma-ray bursts.

Despite the overlapping sky localizations determined from the gravitational-wave detectors and the gamma-ray burst satellites, and the close time relation of the two signals, the question remains whether GW170817 and GRB 170817A originate from the same source. The probability that two unrelated signals would overlap this closely in space and time can be shown to be only 1 in 20 million. Therefore, it is extremely likely that the two signals are due to the same neutron-star merger.

WHAT CAN THIS JOINT OBSERVATION TELL US?

The joint gravitational-wave and GRB observation p
an unprecedented opportunity to study the inner wor
short GRBs and allows us to probe a number of funda
physics concepts, as well as the properties of the r
stars that collided. All this is done by taking into acc
the 1.7 second difference between GW170817 ar
170817A (2) the more than one hundred million ligh
both signals traversed and (3) when we expect each s
be emitted during the neutron-star merger.

Our current best theory of gravity, Einstein's General
of Relativity, predicts the speed of gravitational wa
gamma-rays or light to be identical. Taking just the tim
between the two signals allows us to test the dif
between the speed of gravity and light. The fr
difference between the speed of gravity and light
close to zero, between -0.00000000000000
0.0000000000000007!