**Revised Higher Physics – Unit 1 (Our Universe) tutorial solutions**

**Special relativity**

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| 1a. | 1.5ms-1  0.5ms-1 | | Relative to the bank v = 1.0ms-1 North |
| 1b. | 1.5ms-1  0.5ms-1 | | Relative to the bank v = 2.0ms-1 South |
| 2a. | 0.8ms-1  East | | |
| 2b. | 2.8ms-1 East | | |
| 2c. | 2.2ms-1 West | | |
| 3a. | 3.0ms-1 upwards | | |
| 3b. | 2.0ms-1 downwards | | |
| 4. | A Einstein’s  B same  C zero  D velocity  E speed of light  F slow  G shortened | | |
| 5. | v = 2000kmh-1 | | |
| 6a. | No. The reading on a balance (taken into the lift) would read the same when stationary or moving at uniform velocity. | | |
| 6b. | Yes. When accelerating there will be unbalanced forces and so a balance would read different results. | | |
| 7. | v = 3.0 x 108 ms-1 The speed of light cannot be greater than this value, and is the same in all reference frames, regardless of the relative speed of the observers. | | |
| 8a. | v = 7.5x107 ms-1  s = 3.0x1010 m | s = vt  3.0x1010 = 7.5x107 x t  t = 100s | |
| 8b. | t = 100s (Speed of light does not change) | | |
| 9a. | Speed of light in Earth’s reference frame = 3.0x108 ms-1 | | |
| 9b. | Speed of light in spaceship’s reference frame = 3.0x108 ms-1 | | |
| 10a. | c = 3.0x108 ms-1 | 0.1 x 3.0x108 ms-1  = 0.3x108 ms-1 | |
| 10b. | c = 3.0x108 ms-1 | 0.5 x 1.5x108 ms-1  = 1.5x108 ms-1 | |
| 10c. | c = 3.0x108 ms-1 | 0.6 x 3.0x108 ms-1  = 1.8x108 ms-1 | |
| 10d. | c = 3.0x108 ms-1 | 0.8 x 3.0x108 ms-1  = 2.4x108 ms-1 | |
| 11a. | 3.0x108 ms-1 / 3.0x108 ms-1 = 1c | | |
| 11b. | 2x108 ms-1 / 3.0x108 ms-1 = 0.67c | | |
| 11c. | 1.5x108 ms-1 / 3.0x108 ms-1 = 0.5c | | |
| 11d. | 1.0x108 ms-1 / 3.0x108 ms-1 = 0.33c | | |
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| **Special relativity** | | | |
| 1. | t’ = t / √ (1- v2/c2) Note: v2/c2 = (v/c)2 | | |
| 2a. | t = 20h = 72000 s  v = 1.00x108 ms-1  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  t’ = 72000 / √ [ 1 - ( 1.00x108 / 3.0x108 ) 2 ]  t’ = 7636.753 s = 21.2h  Note: time does not have to be converted from hours into seconds since the term √ (1- v2/c2) is unitless. | |
| 2b. | t = 10 year  v = 2.25x108 ms-1  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  t’ = 10 / √ [ 1 - ( 2.25x108 / 3.0x108 ) 2 ]  t’ = 15.1 years | |
| 2c. | t’= 1400 s  v = 2.00x108 ms-1  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  1400 = t / √ [ 1 - ( 2.00x108 / 3.0x108 ) 2 ]  t = 1043 s | |
| 2d. | t’= 1.40x10-4 s  v = 1.00x108 ms-1  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  1.4x10-4 = t / √ [ 1 - ( 1.00x108 / 3.0x108 ) 2 ]  t = 1.32x10-4s | |
| 2e. | t’= 84 s  t = 60 s  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  84 = 60 / √ [ 1 - ( v/ 3.0x108 ) 2 ]  (60/84)2 = 1 – v2/c2  v2/c2 = 1 - (60/84)2  v2 = [1 - (60/80)2 ] c2  v = 2.10x108 ms-1 | |
| 2f. | t’= 21 min  t = 20 min  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  21 = 20 / √ [ 1 - ( v/ 3.0x108 ) 2 ]  (20/21)2 = 1 – v2/c2  v2/c2 = 1 - (20/21)2  v2 = [1 - (20/21)2 ] c2  v = 9.15x107 ms-1 | |
| 3a. | t’= 15 min  v = 2.0x108 ms-1  c =3.0x108 ms-1 | The rocket is moving, so it’s clock will be running slow, therefore observer P on Earth will measure a longer time than observer Q in the rocket. (t’>t)  t’ = t / √ (1- v2/c2)  15 = t / √ [ 1 - ( 2.00x108 / 3.0x108 ) 2 ]  t = 11min  P sees 11.11 on Q’s watch | |
| 3b. | t= 15 min  v = 2.0x108 ms-1  c =3.0x108 ms-1 | This question can be interpreted in one of two ways.   1. It is the exact opposite of part a, namely there is a switch of reference frames.   t’ = t / √ (1- v2/c2)  15 = t / √ [ 1 - ( 2.00x108 / 3.0x108 ) 2 ]  t = 11min  Q sees 11.11 on P’s watch   1. Observer Q is still moving, so his clock will be running slow, and so he is measuring t and the earth time is dilated (remember t’>t)   t’ = t / √ (1- v2/c2)  t’ = 15 / √ [ 1 - ( 2.00x108 / 3.0x108 ) 2 ]  t’ = 20 min  Q sees 11.20 on P’s watch  We believe that interpretation 2 is the most appropriate, since it is unwise to switch reference frames part way through a problem. | |
| 4. | t = 10 billion years  v = 0.81c ms-1  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  t’ = 10 / √ [ 1 - ( 0.81c/ c ) 2 ]  t’ = 10 / √ [ 1 - 0.812 ]  t’ = 17 billion years  Note: this time is greater than the age of the universe, so the numbers given in the question are clearly fictitious. | |
| 5. | t’= 100 m (the spacecraft is not at rest with respect to the event).  v = 0.75c ms-1  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  14.65 = t / √ [ 1 - ( 0.75c/ c ) 2 ]  14.65 = t / √ [ 1 - 0.752 ]  t = 9.69 s | |
| 6. | t’= 4.0x10-4 s  v = 8.0x107 ms-1  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  4.0x10-4 = t / √ [ 1 - ( 8.0x107 / 3.0x108 ) 2 ]  t = 3.9x10-4  s | |
| 7. | t’= 14 s  t = 10 s  c =3.0x108 ms-1  (remember, t’>t) | t’ = t / √ (1- v2/c2)  14 = 10 / √ [ 1 - ( v/ 3.0x108 ) 2 ]  (10/14)2 = 1 – v2/c2  v2/c2 = 1 - (10/14)2  v2 = [1 - (10/14)2 ] c2  v = 2.10x108 ms-1 | |
| 8.0 | t’= 40.0 s  t = 10.0 s  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  40.0 = 10.0 / √ [ 1 - ( v/ 3.0x108 ) 2 ]  (10.0/40.0)2 = 1 – v2/c2  v2/c2 = 1 - (10.0/40.0)2  v2 = [1 - (10.0/40.0)2 ] c2  v = 2.90x108 ms-1 | |
| 9.0 | t’= 1 year  t = 2 year  c =3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  1 = 2 / √ [ 1 - ( v/ 3.0x108 ) 2 ]  (1/2)2 = 1 – v2/c2  v2/c2 = 1 - (1/2)2  v2 = [1 - (1/2)2 ] c2  v = 2.6x108 ms-1 | |
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**Length Dilation**

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| 1a. | l’ = l √ (1-v2/c2) Note: v2/c2 = (v/c)2  Also note that l’ is contracted length, therefore l’ < l, a useful check. | |
| 2a. | l = 5.00 m  v = 1.00x108 ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  l’ = 5.00 √ (1 - 1.00x108 2/ 3.00x108 2)  l’ = 4.71m |
| 2b. | l = 15.0 m  v = 2.00x108 ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  l’ = 15.0 √ (1 - 2.00x108 2/ 3.00x108 2)  l’ = 11.2 m |
| 2c. | l’ = 0.15km  v = 2.25x108 ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  0.15 = l √ (1 - 2.25x108 2/ 3.00x108 2)  l = 0.23 km |
| 2d. | l’ = 150 mm  v = 1.04x108 ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  150 = l √ (1 – 1.04x108 2/ 3.00x108 2)  l = 160 mm |
| 2e. | l’ = 30 m  l = 35m  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  30 = 35 √ [1 – (v / 3.00x108 )2]  30/35 = √ [1 – (v / 3.00x108 )2]  (30/35)2 = 1 – (v / 3.00x108 )2  v / 3.00x108 = √ [1 - (30/35)2 ]  v = √ [1 - (30/35) 2 ] 3.00x108  v = 1.55x108 ms-1 |
| 2f. | l’ = 10 m  l = 11m  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  10 = 11 √ [1 – (v / 3.00x108 )2]  10/11 = √ [1 – (v / 3.00x108 )2]  (10/11)2 = 1 – (v / 3.00x108)2  v / 3.00x108 = √ [1 - (10/11)2 ]  v = √ [1 - (10/11)2 ] 3.00x108  v = 1.25x108 ms-1 |
| 3. | l = 20 m  v = 1.80x108 ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  l’ = 20 √ [1 – (1.8x108/ 3.00x108)2]  l’ = 16m |
| 4. | l = 2.00 m  v = 0.9c ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  l’ = 2.00 √ [1 – ((0.9c)2/ c2) ]  l’ = 2.00 √ [1 – 0.92]  l’ = 0.87m |
| 5. | l’ = 160 m  v = 0.8c ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  160 = l √ [1 – ((0.8c)2/ c2) ]  160 = l √ [1 – 0.82 ]  l = 267 m |
| 6. | l’ = 0.80 km  v = 0.5c ms-1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  0.80 = l √ [1 – ((0.5c)2/ c2) ]  0.80 = l √ [1 – 0.52 ]  l = 0.92 km |
| 7. | l’ = 0.50 m  l = 1.00m  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  0.50 = 1.00 √ [1 – (v / 3.00x108)2]  0.50/1.00 = √ [1 – (v / 3.00x108)2]  (0.50/1.00)2 = 1 – (v / 3.00x108)2  v / 3.00x108 = √ [1 - (0.50/1.00)2]  v = √ [1 - (0.50/1.00)2 ] x 3.00x108  v = 2.60x108 ms-1 |
| 8. | l’ = 150 m  l = 220m  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  150 = 220 √ [1 – (v / 3.00x108 )2]  150/220 = √ [1 – (v / 3.00x108 )2]  (150/220)2 = 1 – (v / 3.00x108)2  v / 3.00x108 = √ [1 - (150/220)2 ]  v = √ [1 - (150/220)2] x 3.00x108  v = 2.19x108 ms-1 |
| 9. | l’ = 0.99  l = 1  c = 3.00x108 ms-1 | l’ = l √ (1-v2/c2)  0.99 = 1 √ [1 – (v / 3.00x108)2]  0.99 = √ [1 – (v / 3.00x108)2]  (0.99)2 = 1 – (v / 3.00x108)2  v / 3.00x108 = √ [1 - (0.99)2]  v = √ [1 - (0.99)2] 3.00x108  v = 4.23x107 ms-1 |

**Relativity Miscellaneous**

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| 1a. | displacement = 240 m  time taken = 1.00x10-6 s | v = s / t  v = 240 / 1.00x10-6  v = 2.4x108 ms-1 |
| 1b. | t’ = 1.00x10-6 ms-1  v = 2.4x108 ms-1  c = 3.0x108 ms-1 | Note: The clock in the rocket is moving relative to the Earth at high speed, so it’s clock is running slow (i.e. time on Earth is t’ and time in clock is t)  t’ = t / √ (1- v2/c2)  1.00x10-6 = t / √ [ 1 - (2.4x108 / 3.0x108 )2 ]  t = 6x10-7  s |
| 1c. | t = 6x10-7  s  v = 2.4x108 ms-1  l’ = ?  l = 240 m | l’ = l √ (1-v2/c2)  l’ = 240 √ [1 – (2.4x108/3.0x108)2]  l’ = 240  x √ [1 – 0.82]  l’ = 144 m  Note: to check this, the speed of the earth relative to the spacecraft should be 2.4x108 ms-1:  v = distance/time (as measured by spacecraft)  v = 144/6x10-7  v = 2.4x108 ms-1 |
| 2a. | v = 0.95c  t’ = 1 year  c = 3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  1 = t / √ [ 1 - 0.95 2 ]  t = 1 x √ [ 1 - 0.95 2 ]  t = 0.31 years  That is, moving clock on spacecraft is running slow. |
| 2b. | t = 0.31 years  v = 0.95c | d = vt  d = 0.95 x 3.0x108 x 0.31 x 365 x 24 x 60 x 60  d = 2.8x1015  m |
| 2c. | t = 1 year  v = 0.95c | d = vt  d = 0.95 x 3.0x108 x 1 x 365 x 24 x 60 x 60  d = 8.99x1015  m |
| 3a. | t = 2.6x10-8 s  v = 0.99c  c = 3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  t’= 2.6x10 -8  / √ [ 1 - ( 0.99c/c ) 2 ]  t’= 2.6x10 -8  / √ [ 1 - 0.992 ]  t’ = 1.84 x 10-7 s |
| 3b. | v = 0.99c  t’ = 1.84 x 10 -7 s | s = vt  l’ = vt’  l’ = 0.99 x 3.00x108 x 1.84 x 10-7  l’ = 54.6m |
| 4a. | v = 2.4x108 m  t’ = 5.0x10-7 s  c = 3.0x108 ms-1 | distance = speed x time  l = 2.4x108 x 5.0x10-7  l = 120 m |
| 4b. | v = 2.4x108 m  l = 120 m  c = 3.0x108 ms-1  Note the observer on Earth sees the craft as contracted, l’. | l’ = l √ (1-v2/c2)  l’ = 120 x √ [1 – (2.4x108 / 3.0x108)2 ]  l’ = 120 x √ [1 – 0.82 ]  l’ = 72 m |
| 5a. | f = 0.2 Hz | T = 1 / f  T = 1 / 0.2  T = 5s |
| 5b. | v = 0.84c  t = 5s  c = 3.0x108 ms-1  (time t is measured on Earth, at rest with respect to event, hence it is proper time) | t’ = t / √ (1- v2/c2)  t’= 5 / √ [ 1 - ( 0.84c/c)2 ]  t’= 5 / √ [ 1 - 0.842 ]  t’ = 9.22 s |
| 6. | t = 0.15ns  t’= 0.25ns  c = 3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  0.25 = 0.15/ √ [ 1 - ( v/ 3.0x108)2 ]  (0.15/0.25)2 = 1 – v2/c2  v2/c2 = 1 - (0.15/0.25)2  v2 = [1 - (0.15/0.25)2 ] x (3.0x108)2  v = 2.4x108 ms-1 |
| 7a. | v = 0.999c  l = 10.0 km (measured on Earth at rest)  c = 3.0x108 ms-1 | l’ = l √ (1-v2/c2)  l’= 10.0 x √ [1 – ((0.999c)2/c2) ]  l’ = 10.0 x √ [1 – 0.9992 ]  l = 0.447 km = 447 m |
| 7b. | d = 223 km  v = 0.999c | d = vt  447 = 0.999 x 3.0x108  x t  t = 1.49x10-6 s |
| 8a. | l = 4.2 light years  l’ = 3.6 light years  c = 3.0x108 ms-1 | l’ = l √ (1-v2/c2)  3.6 = 4.2 √ [1 – (v / 3.00x108)2]  3.6 / 4.2 = √ [1 – (v / 3.00x108)2]  (3.6 / 4.2)2 = 1 – (v / 3.00x108)2  v2 / c2 = [1 - (3.6 / 4.2)2]  v2 = [1 - (3.6 / 4.2)2] x (3.00x108)2  v = 1.54x108 ms-1 |
| 8b. | l = 4.2 light years  v = 1.54x108 ms-1 | l = vt’  4.2 x 3.0x108  x 365 x 24 x 60 x 60 = 1.54x108  x t’  t’ = 2.58x108 s |
| 8c. | l’ = 3.6 light years  v = 1.54x108 ms-1 | l’ = vt  3.6 x 3.0x108  x 365 x 24 x 60 x 60 = 1.54x108  x t  t = 2.21x108 s |
| 9a. | t = 2.60x10-8 s  v = 0.995c  c = 3.0x108 ms-1 | t’ = t / √ (1- v2/c2)  t’= 2.60x10-8  / √ [ 1 - (0.995c/c)2 ]  t’= 2.60x10-8  / √ [ 1 - 0.995 2 ]  t’ = 2.60x10-7 s  That is, the observer on Earth will measure the lifetime as longer than the muon, since moving clocks run slow. |
| 9b. | v = 0.995c  t’ = 2.60x10-7 s | l = vt’  l = 0.995 x 3.0x108 x 2.60x10-7  l = 77.6m |
| 9c. | l = 77.6 m  v = 0.995c  c = 3.0x108 ms-1  Muon’s measure of length is contracted, so it will measure shorter distance (l’). | l’ = 77.6 x √ (1- v2/c2)  l’ = 77.6 x √ (1- 0.995c 2/c2)  l’ = 77.6 x √ (1- 0.9952)  l = 7.75 m  Alternative method:  d = vt  d = 0.995c x 2.60x10-8  d = 7.76m (difference due to rounding error). |

**The Expanding Universe**

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| 1. | A higher  B lower  C Doppler  D effect | |
| 2a. | f­­­o = fs [v / (v - vs)] |  |
| 2b. | f­­­o = fs [v / (v + vs)] |  |
| 3a. | fs = 400 Hz  v = 340 ms-1  vs = 10 ms-1 | f­­­o = fs [v / (v - vs)]  f­­­o = 400[340 / (340 - 10)]  f­­­o = 412 Hz |
| 3b. | fs = 400 Hz  v = 340 ms-1  vs = 10 ms-1 | f­­­o = fs [v / (v + vs)]  f­­­o = 400[340 / (340 + 10)]  f­­­o = 389 Hz |
| 3c. | fo = 850 Hz  v = 340 ms-1  vs = 20 ms-1 | f­­­o = fs [v / (v - vs)]  850 = fs [340 / (340 - 20)]  fs = 850 / [340 / (340 - 20)]  fs = 800 Hz |
| 3d. | fo = 1020 Hz  v = 340 ms-1  vs = 5 ms-1 | f­­­o = fs [v / (v + vs)]  1020 = fs [340 / (340 + 5)]  fs = 1020 / [340 / (340 + 5)]  fs = 1035 Hz |
| 3e. | fo = 2125 Hz  fs = 2000 Hz  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  2125 = 2000[340 / (340 - vs)]  2125 / 2000 = 340 / (340 - vs )  340 / (2125 / 2000) = 340 - vs  vs = 20 ms-1 |
| 3f. | fo = 170 Hz  fs = 200 Hz  v = 340 ms-1 | f­­­o = fs [v / (v + vs)]  170 = 200[340 / (340 + vs)]  170 / 200 = 340 / (340 + vs )  340 / (170 / 200) = 340 + vs  vs = 60 ms-1 |
| 4. | The frequency of the sound would increase and decrease. | |
| 5a. | fs = 1000 Hz  v = 340 ms-1  vs = 20 ms-1 | f­­­o = fs [v / (v - vs)]  f­­­o = 1000[340 / (340 - 20)]  f­­­o = 1063 Hz |
| 5b. | fs = 1000 Hz  v = 340 ms-1  vs = 20 ms-1 | f­­­o = fs [v / (v + vs)]  f­­­o = 1000[340 / (340 + 20)]  f­­­o = 944 Hz |
| 6a. | fs = 200 Hz  v = 340 ms-1  vs = 25 ms-1 | f­­­o = fs [v / (v - vs)]  f­­­o = 200[340 / (340 - 25)]  f­­­o = 216 Hz |
| 6b. | fs = 200 Hz  v = 340 ms-1  vs = 25 ms-1 | f­­­o = fs [v / (v + vs)]  f­­­o = 200[340 / (340 + 25)]  f­­­o = 186 Hz |
| 7. | fo = 470 Hz  fs = 450 Hz  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  470 = 450[340 / (340 - vs)]  470 / 450 = 340 / (340 - vs )  340 / (470 / 450) = 340 - vs  vs = 14 ms-1 |
| 8. | fo = 540 Hz  fs = 500 Hz  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  540 = 500[340 / (340 - vs)]  540 / 500 = 340 / (340 - vs )  340 / (540 / 500) = 340 - vs  vs = 25.2 ms-1  f­­­o = fs [v / (v + vs)]  fo = 500[340 / (340 + 25.2)]  f­­­o = 466 Hz |
| 9. | fs = 540 Hz  r = 0.75m  v = 340 ms-1  vs = 10 ms-1 | Highest  f­­­o = fs [v / (v - vs)]  f­­­o = 540[340 / (340 - 10)]  f­­­o = 556 Hz  Lowest  f­­­o = fs [v / (v + vs)]  f­­­o = 540[340 / (340 + 10)]  f­­­o = 525 Hz |
| 10a. | vs = 20 ms-1  fs = 300 Hz  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  f­­­o = 300[340 / (340 - 20)]  f­­­o = 318.75 Hz  v = fλ  340 = 318.75 x λ  λ = 1.07 m |
| 10b. | vs = 20 ms-1  fs = 300 Hz  v = 340 ms-1 | f­­­o = fs [v / (v + vs)]  f­­­o = 300[340 / (340 + 20)]  f­­­o = 283.33 Hz  v = fλ  340 = 283.33 x λ  λ = 1.2 m |
| 11a. | vs = 10 ms-1  fs = 1000 Hz  v = 340 ms-1 | f­­­o = fs [v / (v + vs)]  f­­­o = 1000[340 / (340 + 10)]  f­­­o = 971 Hz |
| 11b. | vs = 10 ms-1  fs = 1000 Hz  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  f­­­o = 1000[340 / (340 - 10)]  f­­­o = 1030 Hz |
| 12. | fo / fs = 0.9  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  0.9 = 340 / (340 - vs )  340 / (0.9) = 340 - vs  vs = 37.8 ms-1 |
| 13a. | vs = 3.60 ms-1  v = 340.00 ms-1  fs = 350 kHz = 350000 Hz | The bat hears the echo, the sound wave is moving towards it.  f­­­o = fs [v / (v - vs)]  f­­­o = 350000[340 / (340 - 3.60)]  f­­­o = 353745.54 Hz  f­­­o = 354 kHz |
| 13b. | As the bat's speed decreases the frequency observed decreases.  vs  decreases = v - vs  increases = v / (v - vs ) decreases = fo  decreases | |
| 13c. | vs = 3.60 ms-1  fs = 350 kHz = 350000 Hz  v = 340 ms-1 | f­­­o = fs [v / (v + vs)]  f­­­o = 350000[340 / (340 + 3.6)]  f­­­o = 346332.95 Hz  f­­­o = 346 kHz |
| 14a. | vs = 54 kmh-1 | vs = 54 kmh-1  vs = 54x103 mh-1  vs = 54x103 / (60 x 60) ms-1  vs = 15 ms-1 |
| 14b. | vs = 15ms-1  fs = 1500 Hz  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  f­­­o = 1500[340 / (340 - 15)]  f­­­o = 1569 Hz |
| 14c. | vs = 15ms-1  fs = 1500 Hz  v = 340 ms-1 | f­­­o = fs [v / (v + vs)]  f­­­o = 1500[340 / (340 + 15)]  f­­­o = 1437 Hz |
| 15. | fo = 640 Hz  fs = 600 Hz  v = 340 ms-1 | f­­­o = fs [v / (v - vs)]  640 = 600[340 / (340 - vs)]  640 / 600 = 340 / (340 - vs )  340 / (640 / 600) = 340 - vs  vs = 21.3 ms-1 |
| 16a. | fs = 2200 Hz  r = 0.8 m | s = 2πr  s = 2 x π x 0.8  s = 5.027 m  In one second it does three revolutions, so the total distance = 3 x 5.027 = 15.07m  v = s / t v = 15.07 / 1 v = 15.1 ms-1 |
| 16b. | fs = 2200 Hz  vs = 15.1 ms-1  v = 340 ms-1 | Minimum  f­­­o = fs [v / (v + vs)]  f­­­o = 2200[340 / (340 + 15.1)]  f­­­o = 2106 Hz |
| 16.c | fs = 2200 Hz  vs = 15.1 ms-1  v = 340 ms-1 | Maximum  f­­­o = fs [v / (v - vs)]  f­­­o = 2200[340 / (340 - 15.1)]  f­­­o = 2302 Hz |
| 17. | fo towards = 460 Hz  fo away = 410 Hz  v = 340 ms-1  s = 3x103 m | Moving towards  f­­­o = fs [v / (v - vs)]  460 = fs [340 / (340 - vs)]  460 / [340 / (340 - vs)] = fs  Moving away  f­­­o = fs [v / (v + vs)]  410 = fs [340 / (340 + vs)]  410 / [340 / (340 + vs)] = fs  460 / [340 / (340 - vs)] = 410 / [340 / (340 + vs)]  460 / 410 = [340 / (340 - vs)] / [340 / (340 + vs)]  460 / 410 = (340 + vs) / (340 - vs)  460 x (340 - vs) = 410 x (340 + vs)  (460 x 340) - 460vs = (410 x 340) + 410vs  (460 x 340) - (410 x 340) = 410vs + 460vs  [(460 x 340) - (410 x 340)] / (410+ 460) = vs  vs = 19.5 ms-1  s = vst  3x103 = 19.5 x t  t = 154s |
| 18. | vs = 10 ms-1  fs = 1100 Hz  fo = 1200 Hz | f­­­o = fs [v / (v - vs)]  1200 = 1100 [v / (v - 10)]  1200 x (v - 10) = 1100v  1200v - 12000 = 1100v  1200v - 1100v = 12000  v = 12000 / (1200 - 1100)  v = 120 ms-1 |
| 19. | A longer  B red  C shorter  D blue  E away | |
| 20a. | λrest = 365x10-9 m  λobs = 402x10-9 m | z = (λobs - λrest) / λrest  z = (402x10-9 - 365x10-9) / 365x10-9  z = 0.101  z = 1.01x101 |
| 20b. | λrest = 434x10-9 m  λobs = 456x10-9 m | z = (λobs - λrest) / λrest  z = (456x10-9 - 434x10-9) / 434x10-9  z = 0.0507  z = 5.07 x102 |
| 20c. | z = 8.00x10-2  λrest = 486x10-9 m | z = (λobs - λrest) / λrest  8.00x10-2 = (λobs - 486x10-9) / 486x10-9  (8.00x10-2 x 486x10-9) + 486x10-9 = λobs  λobs = 5.249 x10-7 m  λobs = 525 nm |
| 20d. | z = 4.00x10-2  λrest = 656x10-9 m | z = (λobs - λrest) / λrest  4.00x10-2 = (λobs - 656x10-9) / 656x10-9  (4.00x10-2 x 656x10-9) + 656x10-9 = λobs  λobs = 6.82 x10-7 m  λobs = 682 nm |
| 20e. | z = 5.00x10-2  λobs = 456x10-9 m | z = (λobs - λrest) / λrest  5.00x10-2 = (456x10-9 - λrest) / λrest  5.00x10-2 x λrest = (456x10-9 - λrest)  456x10-9 = 5.00x10-2 λrest + λrest  456x10-9 = λrest (5.00x10-2 + 1)  λrest = 456x10-9 / (5.00x10-2 + 1)  λrest = 4.34 x10-7 m  λrest = 434 nm |
| 20f. | z = 1.00x10-1  λobs = 402x10-9 m | z = (λobs - λrest) / λrest  1.00x10-1= (402x10-9 - λrest) / λrest  1.00x10-1x λrest = (402x10-9 - λrest)  402x10-9 = 1.00x10-1λrest + λrest  402x10-9 = λrest (1.00x10-1+ 1)  λrest = 402x10-9 / (1.00x10-1 + 1)  λrest = 3.65 x10-7 m  λrest = 365 nm |

**Hubbles Law**

|  |  |  |
| --- | --- | --- |
| 1a. | 1 light year | s = vt  s = 3.0x108 x (1 x 365 x 24 x 60 x 60)  s = 9.46x1015 m |
| 1b. | 50 light years | s = vt  s = 3.0x108 x (50 x 365 x 24 x 60 x 60)  s = 4.75x1017 m |
| 1c. | 100000 light years | s = vt  s = 3.0x108 x (100000 x 365 x 24 x 60 x 60)  s = 9.46x1020 m |
| 1d. | 16000000000 light years | s = vt  s = 3.0x108 x (16000000000 x 365 x 24 x 60 x 60)  s = 1.51x1026 m |
| 2a. | d = 1.44x1011 m | number of light years = distance / distance travelled in 1 light year  number = 1.44x1011 / 3.0x108 x (1 x 365 x 24 x 60 x 60)  = 1.52x10-5 light years |
| 2b. | d = 3.97x1016 m | number of light years = distance / distance travelled in 1 light year  number = 3.97x1016  / 3.0x108 x (1 x 365 x 24 x 60 x 60)  = 4.2 light years |
| 2c. | d = 4.91x1023 m | number of light years = distance / distance travelled in 1 light year  number = 4.91x1023 / 3.0x108 x (1 x 365 x 24 x 60 x 60)  = 5.19x107 light years |
| 3a. | d = 7.10x1022 m  Ho = 2.4x10-18 s-1 | v = Hod  v = 2.4x10-18 x 7.10x1022  v = 1.7x105 ms-1 |
| 3b. | c = 3.0x108 ms-1  v = 1.7x105 ms-1 | z = v/c  z = 1.7x105 / 3.0x108  z = 5.67x10-4 |
| 3c. | d = 1.89x1024 m  Ho = 2.4x10-18 s-1 | v = Hod  v = 1.89x1024 x 7.10x1022  v = 4.54x106 ms-1 |
| 3d. | c = 3.0x108 ms-1  v = 4.54x106 ms-1 | z = v/c  z = 4.54x106 / 3.0x108  z = 1.51x10-2 |
| 3e. | v = 1.70x106 ms-1  Ho = 2.4x10-18 s-1 | v = Hod  1.70x106 = 2.4x10-18 x d  d = 1.89x1024 m |
| 3f. | c = 3.0x108 ms-1  v = 1.70x106 ms-1 | z = v/c  z = 1.70x106 / 3.0x108  z = 5.67x10-3 |
| 3g. | v = 2.21x106 ms-1  Ho = 2.4x10-18 s-1 | v = Hod  2.21x106 = 2.4x10-18 x d  d = 9.21x1023 m |
| 3h. | c = 3.0x108 ms-1  v = 2.21x106 ms-1 | z = v/c  z = 2.21x106 / 3.0x108  z =7.37x10-3 |
| 4a. | λobs = 466x10-9 m  λrest = 434x10-9 m | z = (λobs - λrest) / λrest  z = (466x10-9 - 434x10-9) / 434x10-9  z = 7.37x10-2 |
| 4b. | c = 3.0x108 ms-1  z = 7.37x10-2 | z = v / c  7.37x10-2 = v / 3.0x108  v = 2.21x107 ms-1 |
| 4c. | Away, as the observed wavelength is longer than the rest wavelength. | |
| 5a. | λrest = 505x10-9 m  λobs = 530x10-9 m  c = 3.0x108 ms-1 | z = (λobs - λrest) / λrest  z = (530x10-9 - 505x10-9) / 505x10-9  z = 4.95x10-2  z = v / c  4.95x10-2 = v / 3.0x108  v = 1.49x107 ms-1 |
| 5b. | v = 1.49x107 ms-1  Ho = 2.4x10-18 s-1 | v = Hod  1.49x107 = 2.4x10-18 d  d = 6.21x1024 m |
| 6a. | v = 0.074c ms-1 | v = 0.074 x 3x108  v = 2.22x107 ms-1 |
| 6b. | v = 2.22x107 ms-1  Ho = 2.4x10-18 s-1 | v = Hod  2.22x107 = 2.4x10-18 d  d = 9.25x1024 m |
| 7a. | v = 2.4x107 ms-1  c = 3.0x108 ms-1 | z = v / c  2.4x107 = v / 3.0x108  z = 8.0x10-2 |
| 7b. | λobs = 530x10-9 m  z = 8.0x10-2 | z = (λobs - λrest) / λrest  8.0x10-2 = (530x10-9 - λrest) / λrest  8.0x10-2 x λrest = (530x10-9 - λrest)  530x10-9 = 8.0x10-2 λrest + λrest  530x10-9 = λrest (8.0x10-2 + 1)  λrest = 530x10-9 / (8.0x10-2 + 1)  λrest = 4.10 x10-7 m  λrest = 410 nm |
| 8a. | λrest = 489x10-9 m  λobs = 538x10-9 m  c = 3.0x108 ms-1 | z = (λobs - λrest) / λrest  z = (538x10-9 - 489x10-9) / 489x10-9  z = 1.00x10-2  z = v / c  1.00x10-2 = v / 3.0x108  v = 3.0x107 ms-1 |
| 8b. | v = 3.0x107 ms-1  Ho = 2.4x10-18 s-1 | v = Hod  3.0x107 = 2.4x10-18 d  d = 1.25x1025 m  d = 1.25x1025 /3.0x108 x 365 x 24 x 60 x 60  d = 1.32x109 light years |
| 9. | d = 1x1010 light years  Ho = 2.4x10-18 s-1 | d = 1x1010 x 3.0x108 x 365 x 24 x 60 x 60  d = 9.4608x1025 m  v = Hod  v = Ho = 2.4x10-18 x 9.4608x1025  v = 2.27x107 ms-1 |
| 10a. | c = 3.0x108 ms-1  frest = 5.00x1014 Hz | v = fλ  3.0x108 = 5.00x1014 x λ  λ = 6.00x10-7 m |
| 10b. | c = 3.0x108 ms-1  λrest = 6.00x10-7 m  v = 3.0x107 ms-1 | z = v / c  z = 3.0x107 / 3.0x108  z = 0.1  z = (λobs - λrest) / λrest  0.1 = (λobs - 6.00x10-7) / 6.00x10-7 ]  (0.1x 6.00x10-7) + 6.00x10-7= λobs  λobs = 6.6x10-7 m  v = fλ  3.0x108 = f x 6.6x10-7  f = 4.55x1014 Hz |
| 11a. | λrest = 486x10-9 m  λobs = (486x10-9 +20x10-9 )m  c = 3.0x108 ms-1 | z = (λobs - λrest) / λrest  z = (506x10-9 - 486x10-9) / 486x10-9  z = 4.11x10-2  z = v / c  4.11x10-2 = v / 3.0x108  v = 1.23x107 ms-1 |
| 11b. | Ho = 2.4x10-18 s-1  v = 1.23x107 ms-1 | v = Hod  1.23x107 = 2.4x10-18 x d  d = 5.125x1024 m  d = 5.125x1024 / (3.0x108 x 365 x 24 x 60 x 60)  d = 5.42x108 m  d = 542 million light years |
| 12. | λrest = 656x10-9 m  λobs = 660x10-9 m  c = 3.0x108 ms-1 | z = (λobs - λrest) / λrest  z = (660x10-9 - 656x10-9) / 656x10-9  z = 6.098x10-3  z = v / c  6.098x10-3= v / 3.0x108  v = 1.83x106 ms-1 |
| 13. | v = 2 kms-1 = 2000 ms-1  λrest = 486.1x10-9 m  c = 3.0x108 ms-1 | z = v / c  z = 2000 / 3.0x108  z = 6.67x10-6  6.67x10-6 = (λobs - λrest) / 486.1x10-9  wavelength shift = (λobs - λrest) = 6.67x10-6 / 486.1x10-9  wavelength shift = 3.24x10-12 |

**The Big Bang Theory**

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| 1a. | P | |
| 1b. | As temperature increases, the energy released increases. | |
| 1c. | The total energy increases. | |
| 1di. | When temperature increases the energy increases. When energy increases the wavelength decreases. (E=hf and v=fλ, leading to E=hv/λ) | |
| 1dii. | 6000 x 4.8x10-7 = 2.88x10-3 = 2.9x10-3  5000 x 5.8x10-7 = 2.9x10-3  4000 x 7.3x10-7 = 2.92x10-3 = 2.9x10-3  3000 x 9.7x10-7 = 2.91x10-3 = 2.9x10-3  Tλmax = 2.9x10-3 | |
| 1ei. | λmax = 2.7x10-7 m | Tλmax = 2.9x10-3  T x 2.7x10-7= 2.9x10-3  T = 10741 K |
| 1eii. | T = 23000 K | Tλmax = 2.9x10-3  23000 x λmax = 2.9x10-3  λmax = 1.3x10-7 m |
| 1eiii. | λ= 1.1x10-3 m | Tλmax = 2.9x10-3  T x 1.1x10-3= 2.9x10-3  T = 2.6 K |
| 1eiv. | T =33 oC = 33+273 = 306 K | Tλmax = 2.9x10-3  306 x λmax = 2.9x10-3  λmax = 9.5x10-6 m  Infra red radiation |