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A3_1 Doppler Shift Of Usain Bolt

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Abstract

In 2009, Usain Bolt broke the world record with a finishing time of 9.58 seconds in the 100m race at the World Track and Field Championships in Berlin. In this paper, we calculate the change in wavelength of the colour of Usain Bolt's shirt as seen by an observer at the starting point of the race. This phenomenon is also known as the Doppler Effect. We find that throughout the race, the maximum change in the wavelength of Bolt's shirt is equal to 24fm; this is much less than the human eye can detect.

Introduction

In 1842, an Austrian Physicist named Christian Doppler proposed that when a source is moving relative to an observer, then the wavelength or frequency emitted by the source changes.[1] If the source is moving away from the observer, then the emitted wavelength will increase or shift towards the redder part of the visible spectrum. This is also known as redshift.

The redshift caused during the sprint by Usain Bolt in his world record breaking run at Berlin is very small, but can be mathematically calculated. This means that to an observer at the starting point, the colour of Bolt's shirt would change. However, this change would not be noticeable to the human eye.

Using data from the International Association of Athletics Federations (IAAF) [2], we calculate the change in wavelength of the colour of Bolt's shirt at an interval of 20m. We assume the rest wavelength of Usain Bolt's shirt to be 580nm (Yellow).

Theory

If λ_0 is the rest wavelength of Usain Bolt's shirt then the change in wavelength ($\Delta\lambda$) of the colour of his shirt can be found using

$$z = \frac{v}{c} = \Delta\lambda \tag{1}$$

$$\Delta\lambda = \lambda_0 \frac{v}{c} \tag{2}$$

Where v is the velocity of Usain Bolt, c is the speed of light, λ_0 is the rest wavelength (580 nm) and $\Delta\lambda$ is the change in wavelength

Time interval ± 0.01 (s)	Distance ± 0.003 (m)
2.89	0-20
1.75	20-40
1.67	40-60
1.61	60-80
1.66	80-100

Figure 1: This table shows the time taken for Usain Bolt to cover each 20m in the 100m race

We calculated the error in the measurement of the time from the accuracy of the stopwatch used and the error of the distance from the resolution of the camera's used to film the race. The camera used gives a resolution at the track of 3mm [3]. Next we convert distance and time into velocity using

$$v = \frac{d}{t} \tag{3}$$

where v is velocity, d is distance and t is time, and then calculate the change in wavelength for each interval using Equation 2. This can be seen in figure 2.

Distance (m)	Velocity (ms^{-1})	$\Delta\lambda$ (fm)
0-20	6.92±0.024	13.4±0.047
20-40	11.43±0.065	22.1±0.126
40-60	11.98±0.072	23.2±0.139
60-80	12.42±0.077	24.0±0.149
80-100	12.05±0.762	23.3±0.141

Figure 2: This table shows how the velocity and doppler shift of Usain Bolt progresses throughout the race

We calculated the error on the velocity using standard error analysis techniques for multiplication and division and the error on the shift in wavelength was calculated in the same way.

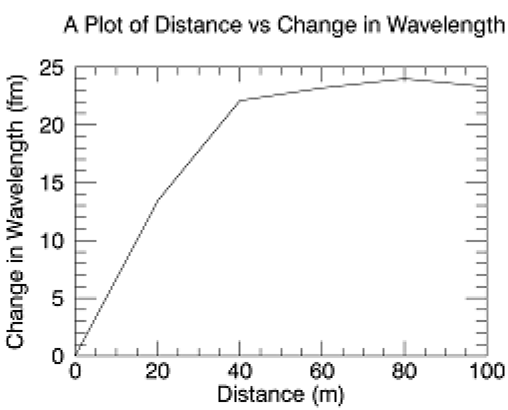

Figure 3: This graph shows how the doppler shift of Usain Bolt varies throughout the race.

Discussion

As shown by figure 3, the largest shift in wavelength of Usain Bolt's shirt would be 24.0fm and at the smallest shift it would be 13.4fm. Although the visible light on the electromagnetic spectrum is continuous, the colour yellow is considered to span a total of 20nm, from 577nm to 597nm [4]. Dividing the change in wavelength by 20nm, to cover the entire yellow range, we can see that the percentage difference is equal to 0.00012% of the hue. The human eye can detect changes of approximately 1nm at 580nm in normal daylight levels [5], so this is unfortunately around 40,000 times too small to be detected by the human eye. To cause a visible change, Usain would have to run faster by a factor of 41,600, at a velocity of 517km s^{-1}.

Conclusion

We conclude that there is a change in wavelength of Bolt's shirt throughout the race, however, the shift in wavelength is negligable and so no change can be seen. Future work could be done to determine whether a computer would be able to detect the change; this is made too complicated for the scope of this work as hexadecimals would have to be considered. Further work could also be done to determine whether an animal would be able to detect the change in wavelength.

References

[1] `http://www.biography.com/people/christian-doppler-9277346` accessed on 17/10/2016

[2] `http://www.sportsscientists.com/wp-content/uploads/2009/08/usain-bolt-100m-wr-biomechanical-analysis.png` accessed on 04/10/2016

[3] `http://petapixel.com/2016/08/18/camera-ensures-photo-finish-olympics/1` accessed on 18/10/2016

[4] `http://physics.tutorvista.com/waves/wavelength-of-light.html` accessed on 05/10/2016

[5] `http://www.giangrandi.ch/optics/eye/eye.shtml` accessed on 05/10/2016