



Physics of Sports

Dr. Muhammad Ali Yousuf

mali@jhu.edu

http://pages.jh.edu/~maliyou1/Physics_of_Sports/

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- If you feel a reference is missing, please let me know and I'll either remove the content or will provide the reference.

The physics of sports isn't rocket science.
It's much harder.

Bob Adair in *The Physics of Baseball*

Introduction

Course Number: AS.360.167.13

Dates: Monday 1/8/2018 - Friday 1/26/2018

Times: Monday - 6-8:30 | Friday - 6-8:30

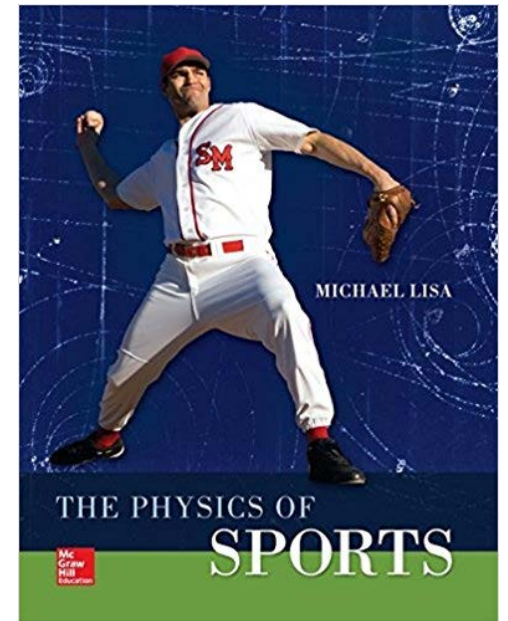
Location: Homewood Campus, Hodson 213

Webpage: <http://pages.jh.edu/~maliyou1/>

Textbook: Michael Lisa, [The Physics of Sports.](#)

ISBN-13: 978-0073513973

Grading: Class participation 30%, two written assignments (15%+15%), project (40%).



Introduce yourself:

- Write, in one single line (since there are many participants, if you write on multiple lines, messages will get mixed up):
 - (1) your preferred name,
 - (2) your area of study and/or research, and
 - (3) something interesting about you which will help others remember you.
- I'll start with myself ...
- (1) My name is Ali, (2) though I am a theoretical physicist by education, my field of research is Biomedical Engineering/Medical Devices. (3) I am a big fan of Star Wars movies and deeply inspired by Yoda, I am.

History of the Physics of Sports

- In early 1850s the subject of rotating artillery shells was explored by the German professor Heinrich Magnus. In this project he investigated sideways deflection of artillery shells which were rotating.
- In 1877 Lord Rayleigh wrote a paper on the irregular flight of a tennis-ball. It can be found [here](#).
- It is also a good topic for projects.

Plan for Today

A. Introduction to Physics of Sports and a survey of kinematics

1. Warm-up: Basic Concepts

- I. Quantifying the world of sports
- II. When we don't have exact numbers
- III. The center of mass

2. Racing, Mathematically

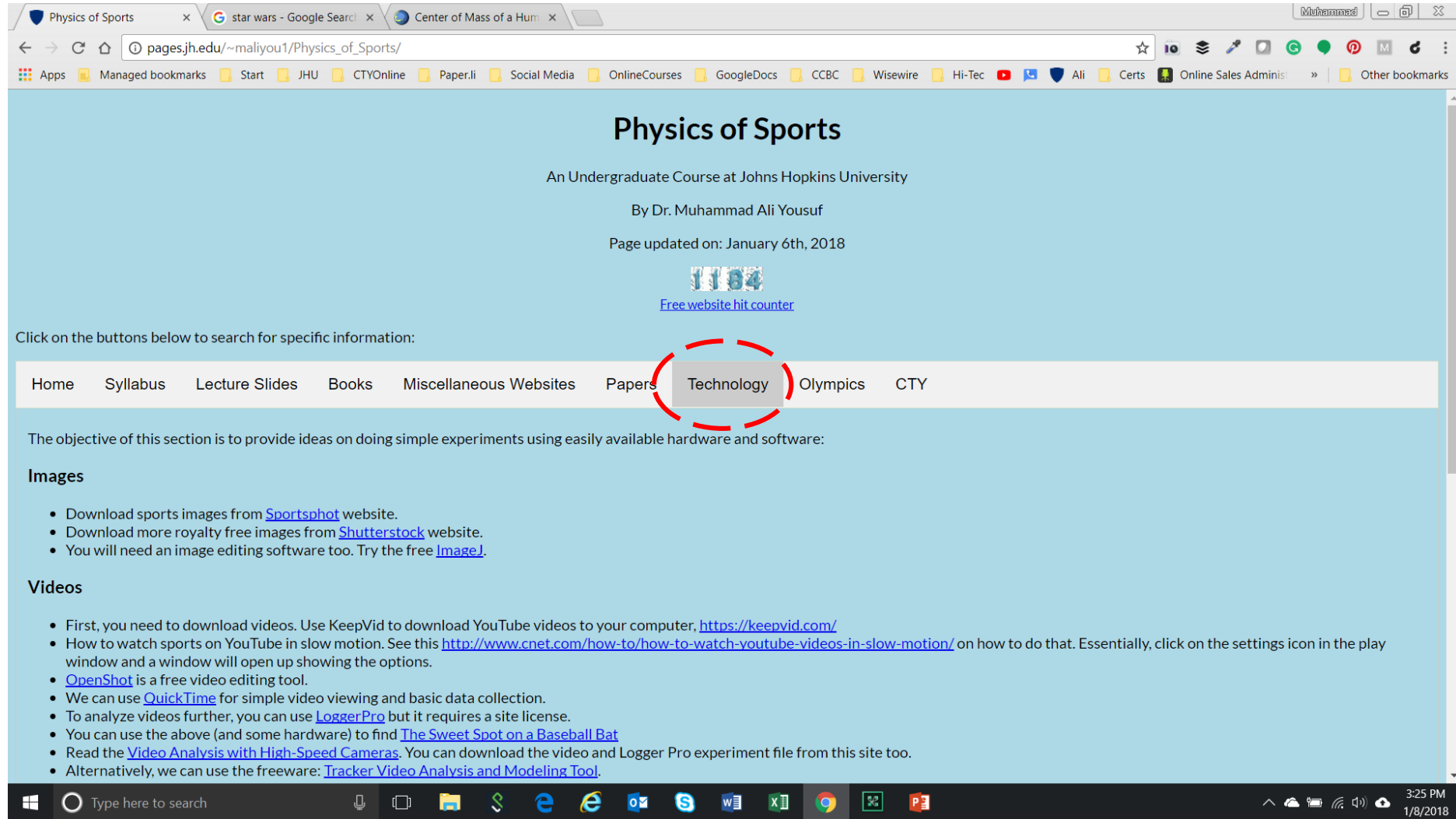
- I. Phelps in Beijing (Swimming, <https://www.youtube.com/watch?v=AVExBUxlcls&list=PLm4DmlOa3zay-bL9vDVPTShhEzZhjgtDa>)
- II. Bolt in Berlin (https://www.youtube.com/watch?v=3nbjhpcZ9_g)
- III. Rope-climbing and diving

 **B. Measurement tools available, photo and video analysis.**

Measurement tools available, photo and
video analysis

Resources on the Website

http://pages.jh.edu/~maliyou1/Physics_of_Sports/



The screenshot shows a web browser window with the URL http://pages.jh.edu/~maliyou1/Physics_of_Sports/. The page has a light blue background and a navigation bar with links: Home, Syllabus, Lecture Slides, Books, Miscellaneous Websites, Papers, Technology (highlighted with a red dashed circle), Olympics, and CTY. Below the navigation bar, the text reads: "The objective of this section is to provide ideas on doing simple experiments using easily available hardware and software:". There are two sections: "Images" and "Videos". The "Images" section lists three bullet points: "Download sports images from [Sportsphot](#) website.", "Download more royalty free images from [Shutterstock](#) website.", and "You will need an image editing software too. Try the free [ImageJ](#).". The "Videos" section lists seven bullet points: "First, you need to download videos. Use KeepVid to download YouTube videos to your computer, <https://keepvid.com/>", "How to watch sports on YouTube in slow motion. See this <http://www.cnet.com/how-to/how-to-watch-youtube-videos-in-slow-motion/> on how to do that. Essentially, click on the settings icon in the play window and a window will open up showing the options.", "OpenShot is a free video editing tool.", "We can use [QuickTime](#) for simple video viewing and basic data collection.", "To analyze videos further, you can use [LoggerPro](#) but it requires a site license.", "You can use the above (and some hardware) to find [The Sweet Spot on a Baseball Bat](#)", "Read the [Video Analysis with High-Speed Cameras](#). You can download the video and Logger Pro experiment file from this site too.", and "Alternatively, we can use the freeware: [Tracker Video Analysis and Modeling Tool](#).".

Physics of Sports

An Undergraduate Course at Johns Hopkins University

By Dr. Muhammad Ali Yousuf

Page updated on: January 6th, 2018

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[Free website hit counter](#)

Click on the buttons below to search for specific information:

Home Syllabus Lecture Slides Books Miscellaneous Websites Papers **Technology** Olympics CTY

The objective of this section is to provide ideas on doing simple experiments using easily available hardware and software:

Images

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Videos

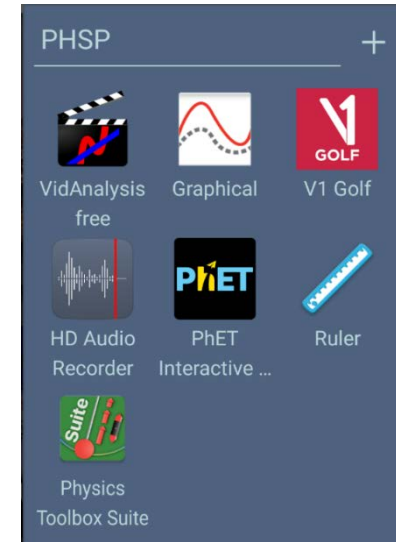
- First, you need to download videos. Use KeepVid to download YouTube videos to your computer, <https://keepvid.com/>
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- ~~Free Android App, [Vernier Graphical Analysis](#). It provides interface to LoggerPro but you can also do experiments with onboard sensors.~~
- ~~Free iPhone App, [Vernier Graphical Analysis](#). It provides interface to LoggerPro but you can also do experiments with onboard sensors.~~



Sound

- You will need the Audacity software to record and analyze the sound spectrum. Audacity is free, open source, cross-platform software for recording and editing sounds. It can be found here: <http://audacity.sourceforge.net/>
- To measure time between two events (like hitting a ball which then strikes a wall) you can use computer's internal sound card to record and analyze it.
- See: Using the Sound Card as a Timer by Aguiar and Pereira, at <http://scitation.aip.org/content/aapt/journal/tpt/49/1/10.1119/1.3527753>

Simulations

- The following PhET and other simulations each has some relevant physics concept explained:
 - [Projectile Motion](#)
 - [Forces and Motion](#)
 - [Energy Skate Park](#)
 - [Sports Software Download](#)

Projectile Motion

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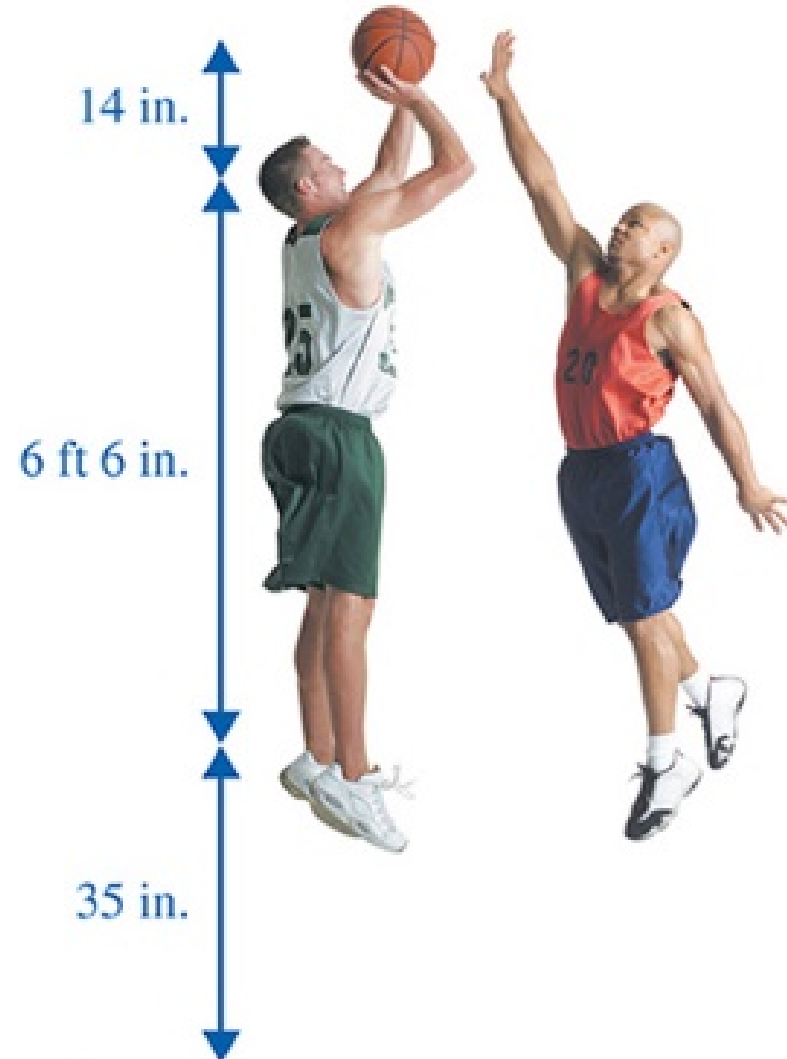
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Heights

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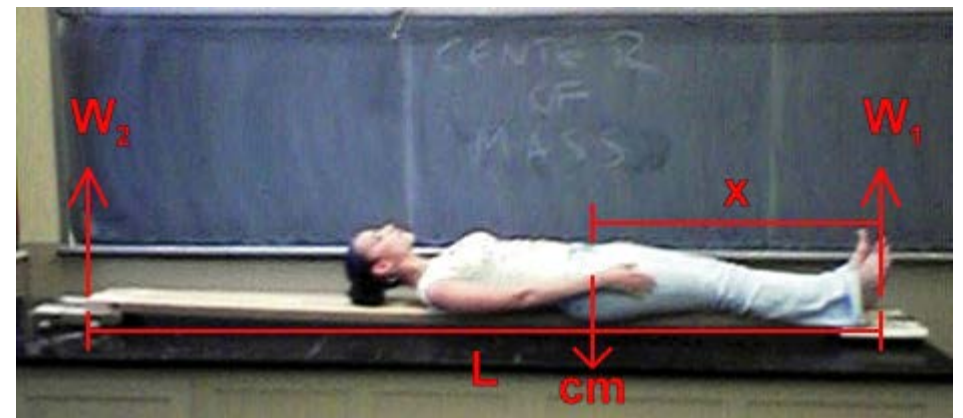


“Typical” sizes of a basketball player taking a jump shot.

© Rubberball/Getty Images RF

Where is the center of mass of a human?

- A person's center of mass is slightly below his/her belly button, which is nearly the geometric center of a person.
- Males and females have different centers of mass- females' centers of mass are lower than those of males.
- The average ratio of center of mass to height in females is approximately 0.543 and the average ratio of center of mass to height in males is approximately 0.560.



Differences between sports

- Does height matter in sports?
- <https://www.youtube.com/watch?v=IcTNlk0yFj0>



<http://www.pxleyes.com/blog/2012/03/50-brilliant-examples-of-sequence-photography/>

Questions (Estimates)



1. What is the height of the sportsman? (that fixes a scale for the photo)
2. Assuming the first image at the origin of the coordinates, what is the maximum height reached?
3. What is the range?
4. What is the launch angle?
5. What are the horizontal and vertical accelerations?
6. What is the initial launch velocity \mathbf{v} ? (you need kinematic equations here).
7. What is the time of flight? (you need kinematic equations here).
8. What is the frame rate (fps) used by the camera?

$$x = v_{0x}t + \frac{1}{2}a_x t^2$$

$$x = \frac{v_{0x} + v_{fx}}{2}t$$

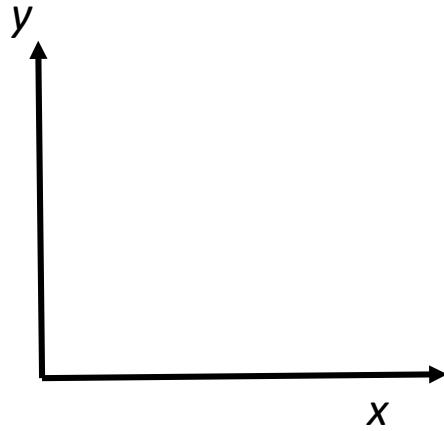
$$v_{fx} = v_{0x} + a_x t$$

$$2a_x x = v_{fx}^2 - v_{0x}^2$$

$$\text{Range} = x_{\max} = \frac{v_0^2 \sin 2\theta}{g}$$

$$\text{Height} = y_{\max} = \frac{v_0^2 \sin^2 \theta}{2g}$$

$$\text{Time of flight} = T = \frac{2v \sin \theta}{g}$$



$$y = v_{0y}t + \frac{1}{2}a_y t^2$$

$$y = \frac{v_{0y} + v_{fy}}{2}t$$

$$v_{fy} = v_{0y} + a_y t$$

$$2a_y y = v_{fy}^2 - v_{0y}^2$$

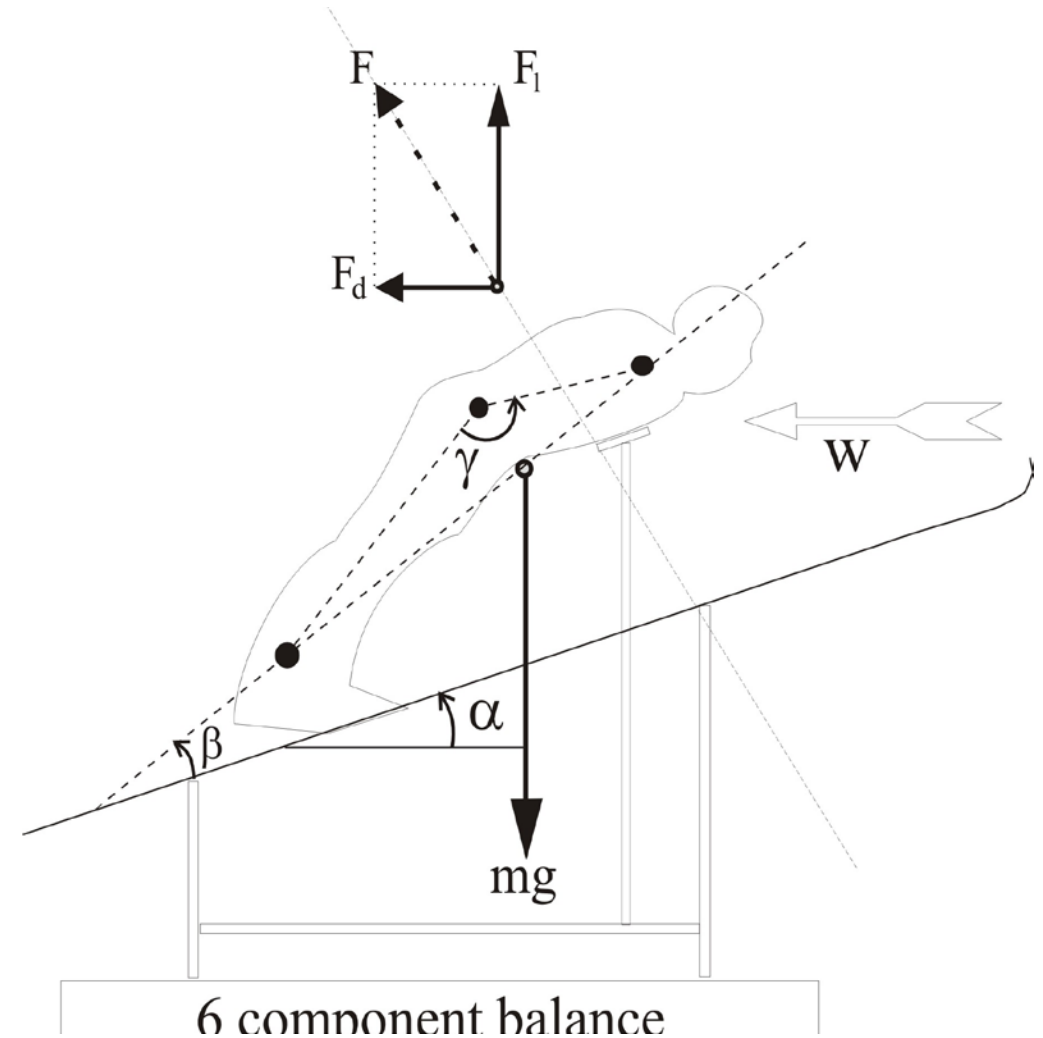
x	v_{0x}	a_x	t	v_{fx}



y	v_{0y}	a_y	t	v_{fy}

The physics of ski jumping,

<https://pdfs.semanticscholar.org/e956/0e12923567efef9e37bead23b9e85bfe0ca3.pdf>



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Swimming

Phelps in Beijing (section 2.1)

MICHAEL PHELPS Olympic medals won

1 gold and **2** silvers at 2012 London Olympics



► 4x200m Free. Relay
6m59.70s

► 200m Butterfly
1m53.01s

NEXT EVENTS FOR PHELPS

► 200m Ind. Med.

► 100m Butterfly

► 4x100m Med. Relay

► 4x100m Free. Relay
3m10.38s

8 golds at 2008 Beijing Olympics



► 100m Butterfly
50.58sec.

► 4x100m Med. Relay
3m29.34s ○

► 200m Butterfly
1m52.03s ○

► 4x200m Free. Relay
6m58.56s ○

► 200m Ind. Medley
1m54.23s ○

► 200m Freestyle
1m42.96s ○

► 400m Ind. Medley
4m03.84s ○

► 4x100m Free. Relay
3m08.24s ○

6 golds and **2** bronzes at 2004 Athens Olympics



► 100m Butterfly
51.25sec. ○

► 4x100m Med. Relay*
3m30.68s ○

► 200m Butterfly
1m54.04s ○

► 4x200m Free. Relay
7m07.33s

► 200m Ind. Medley
1m57.14s ○

► 200m Freestyle
1m45.32s

► 400m Ind. Medley
4m08.26s ○

► 4x100m Free. Relay
3m14.62s

BIO

► BORN

June 30, 1985
Baltimore, MD, U.S.A.

► HEIGHT

1.93m

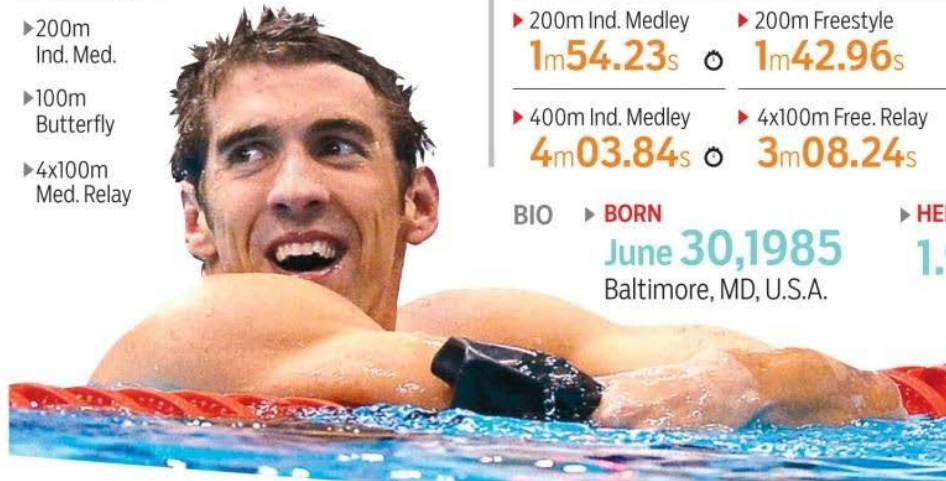
► WEIGHT

83.9kg

○ – Olympic record ○ – World record

NOTE: Record times set at events and may not be current

*Swam in heats but not in final



Sources: USA Swimming, Federation Internationale de Natation (FINA), International Olympic Committee

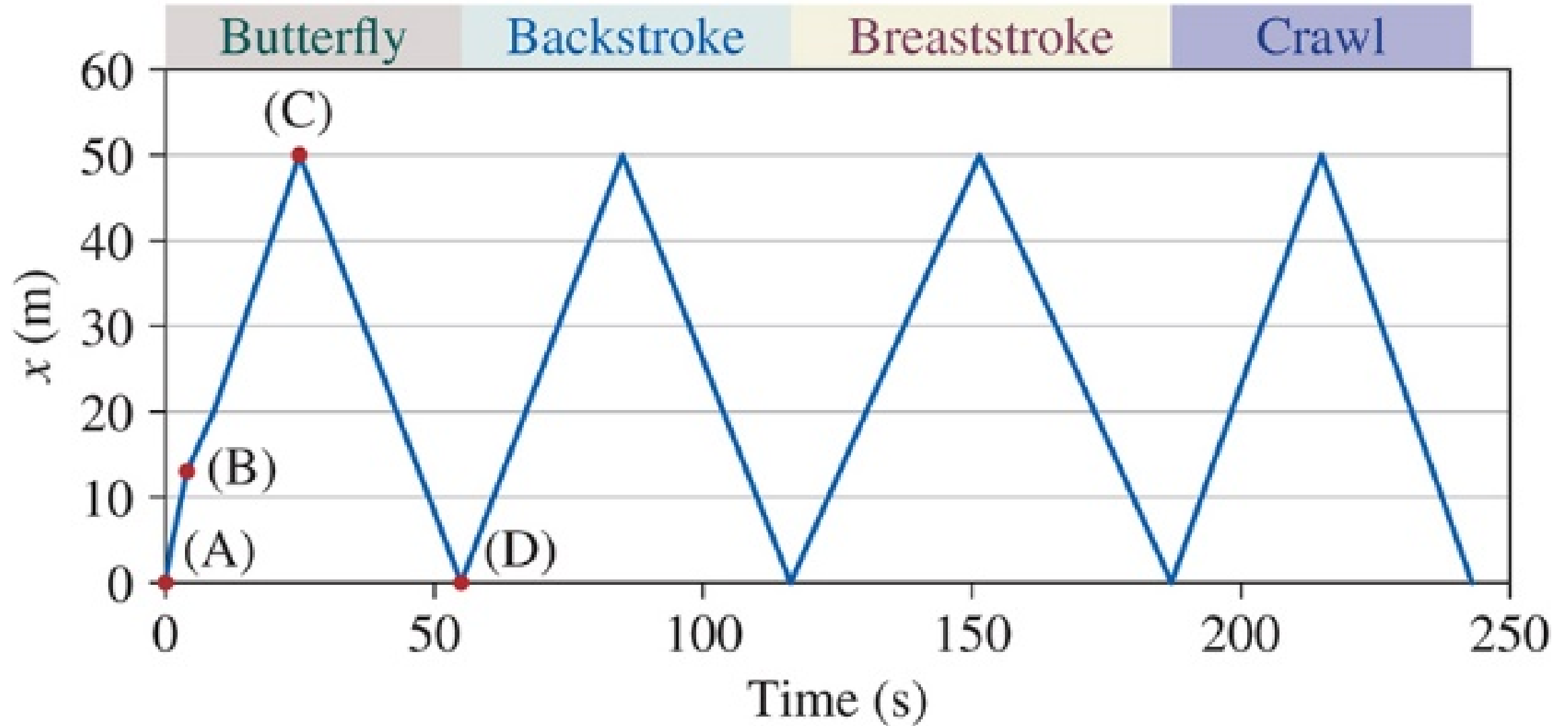
Photo: Reuters

Reuters/©Gulf News

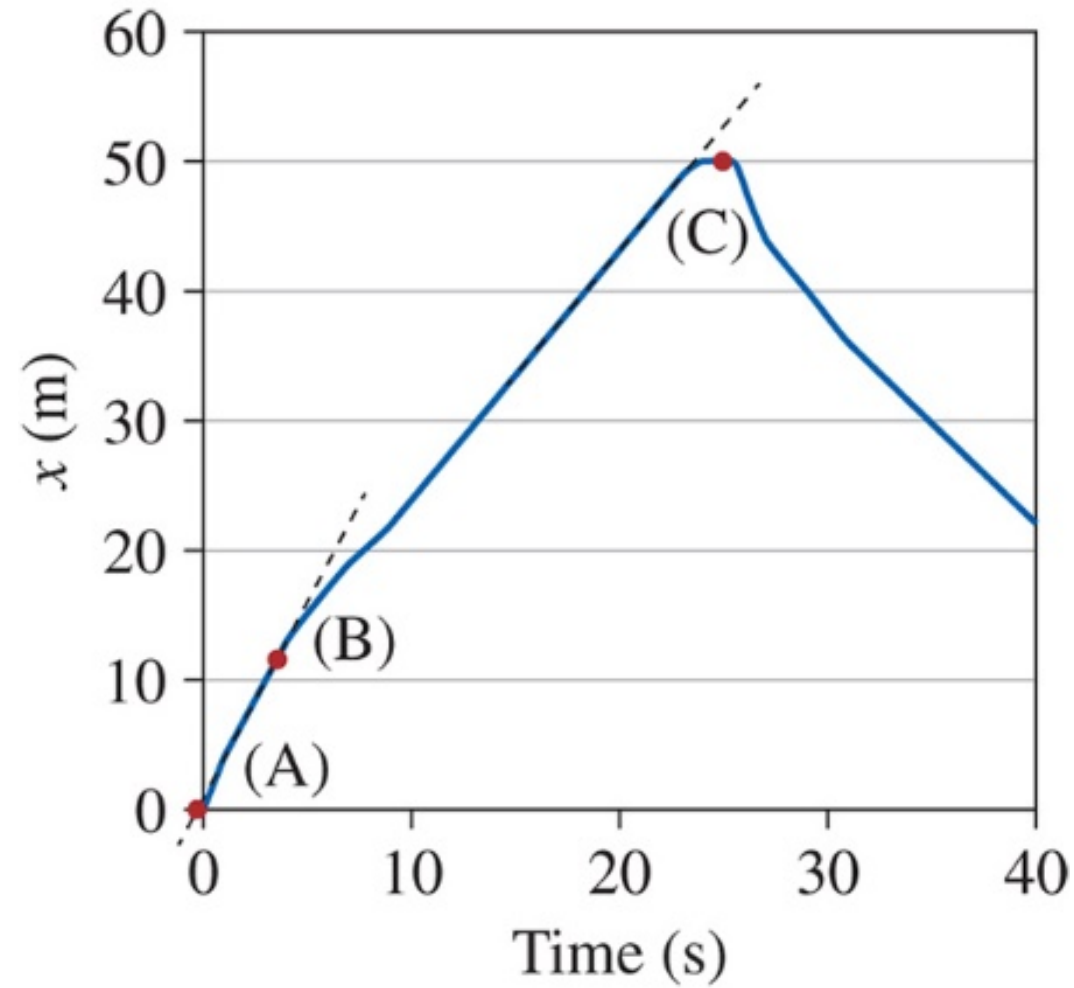
}

Calculations

- Let's find Phelps's speed during the second length in m/s:



Michael Phelps's world-record-setting 400-m medley race in the 2008 Summer Olympics. Phelps's displacement relative to the edge of the pool is plotted on the vertical axis, versus time on the horizontal.



Instantaneous velocity

A blown-up portion of the graph shown in figure 2.1. Two tangent lines are drawn. What do they represent?

Running

Bolt in Berlin



<http://www.all-athletics.com/en-us/photos/usain-bolt-berlin-2009-19>

How to run the 100m

The SPIKES guide to beating Bolt, brought to you by leading UK Athletics coach Dan Pfaff

The 100m is all about just running like the clappers, right? Well, **SPIKES** spoke to coach Dan Pfaff, the director at UK Athletics' High Performance Centre in north London and found it is actually very technical and somewhat tricky to master. The 100m can be broken down into the five phases on

the right, according to Pfaff – who should know a thing or two about it having been coach to 1996 Olympic 100m champion Donovan Bailey. Some sprinters are masters of particular phases, but no one has yet mastered them all. So if you plan to take Usain Bolt's 9.58 world record, this is the place to start.

Reaction time

Put simply, this is an athlete's ability to react to the starting gun. Some believe it is an innate skill which cannot be improved. However, Pfaff is not so sure.

"In my experience, with better mechanics and block set-up you can improve. Whether the improvement is massive, I don't think so."

Block clearance

This is the initial explosion from the blocks to the first step. An athlete supplies force on both block pedals and in the process the body is launched in the air. The angle of launch is determined by block settings, hand and head position, and Pfaff believes this is critical. "The most efficient projectile angle is 45

degrees. If people project too low they climb along the ground. The opposite is someone who gets up very rapidly and get less drive from the blocks. The biomechanics can be taught and mastered. Hip strength is a huge asset."

The drive phase

This is the period – often up to 50m – when an athlete builds up speed to the maximum. Each stride in this phase should be longer and quicker and the angle of the body to the ground will increase with each step.

"The world's best sprinters and sprint coaches spend a lot of time on this area. It is very, very complex. All the elements

in a sprint are difficult to master, but this phase can easily go wrong, particularly when you are in a state of arousal and excitement. The end of this phase is known as the transition, when the sprinter moves into an upright posture and reaches the run's fastest speed."

Max velocity

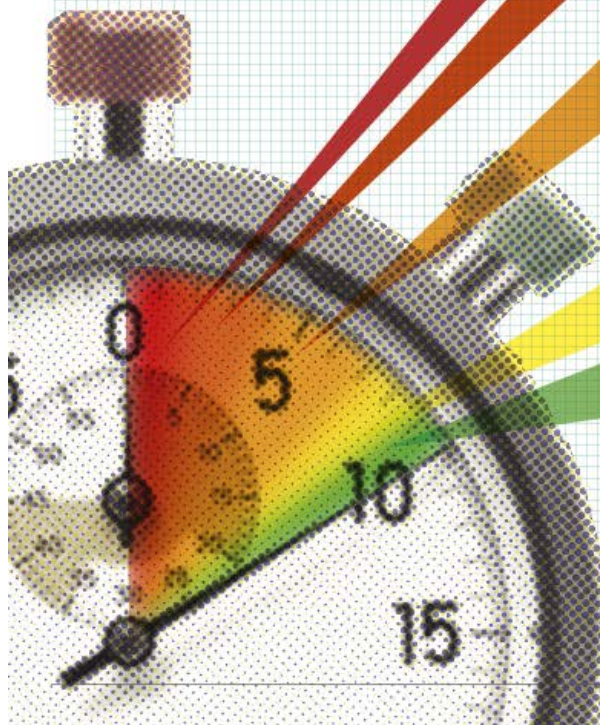
The point where an athlete is sprinting at top speed. Most biomechanical reports say this is from 50-60m for women and 60-70m for men, however Usain Bolt can

extend this to beyond 80m. "You have to have excellent posture and excellent timing of the arms and the legs in this phase of the race."

Deceleration

The fifth and final phase of the race. Often it looks like an athlete may be running away from the group in the last 20m but in reality they are slowing down

slightly less than their rivals. "Relaxation is a key component. Also training at high velocity is imperative for improving in this final phase."



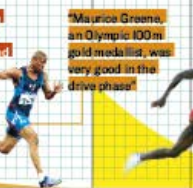
Who's the best at what



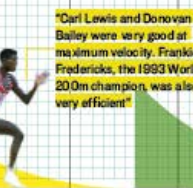
"Donna Mitchell, the 1992 Olympic 100m bronze medalist, seemed to excel in the reaction time phase of the race."



"I think Ronnie Spear, the two-time World 100m silver medalist, was very good at the block clearance phase of the race."



"Marion Jones, an Olympic 100m gold medalist, was very good in the drive phase."



"Carl Lewis and Donovan Bailey were very good at maximum velocity. Frankie Fredericks, the 1993 World 200m champion, was also very efficient."



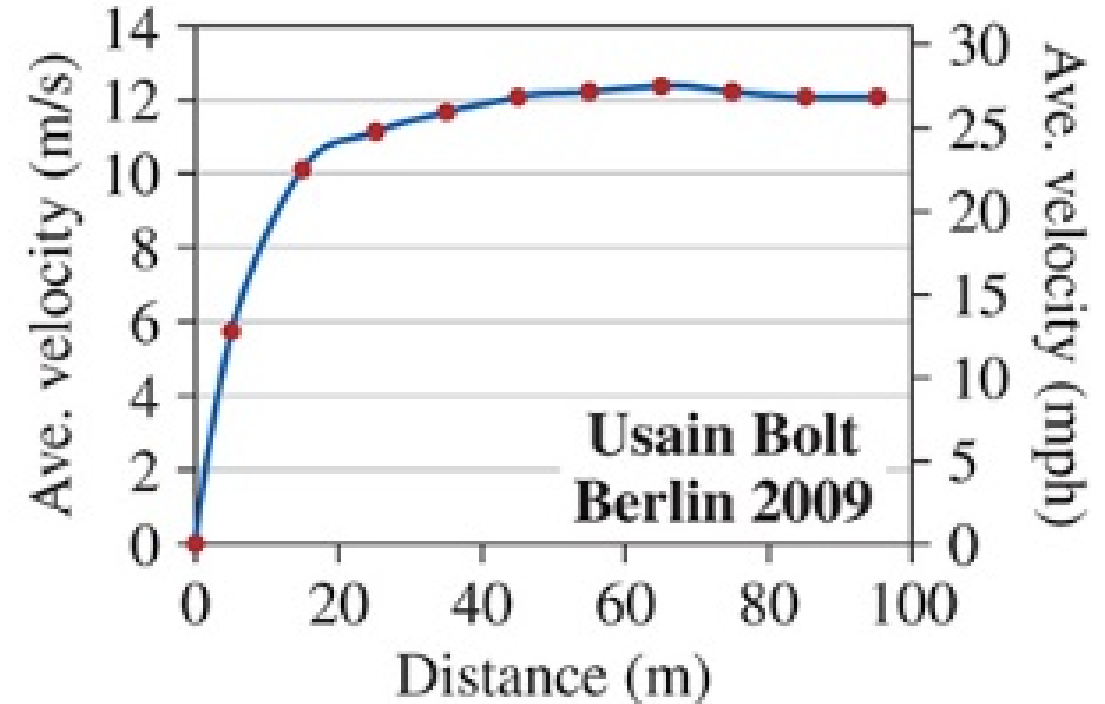
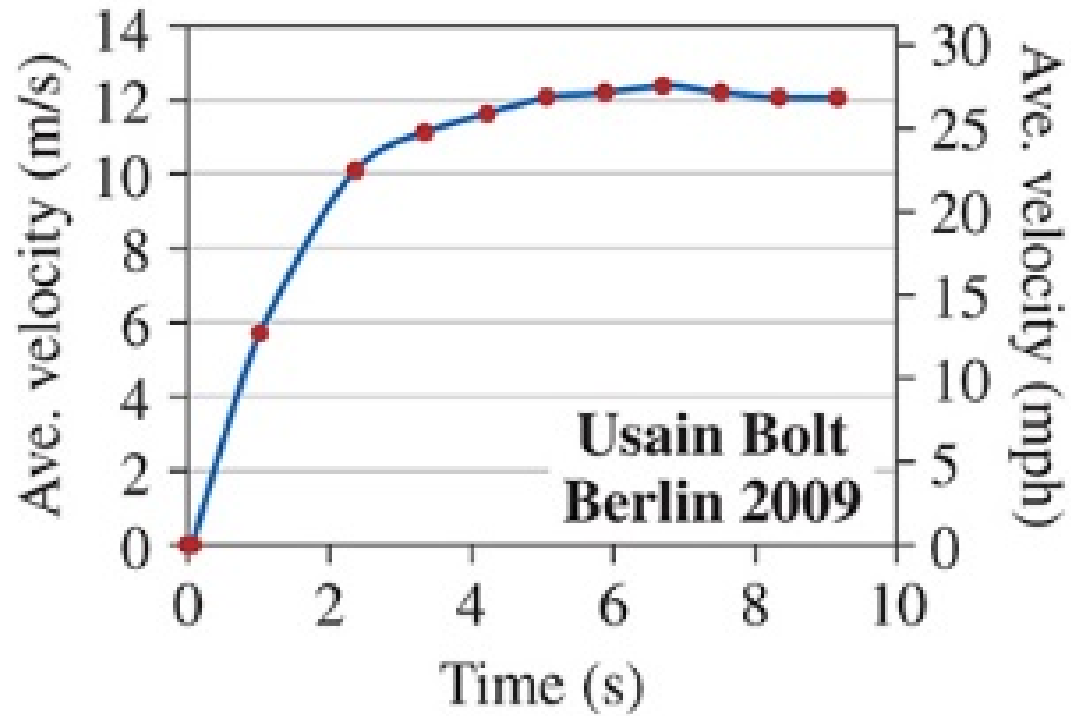
"Usain Bolt is a master of the final phase of the race."

Getty Images, Press Association, Shutterstock

Usain Bolt's Winning Time & Margin of Victory

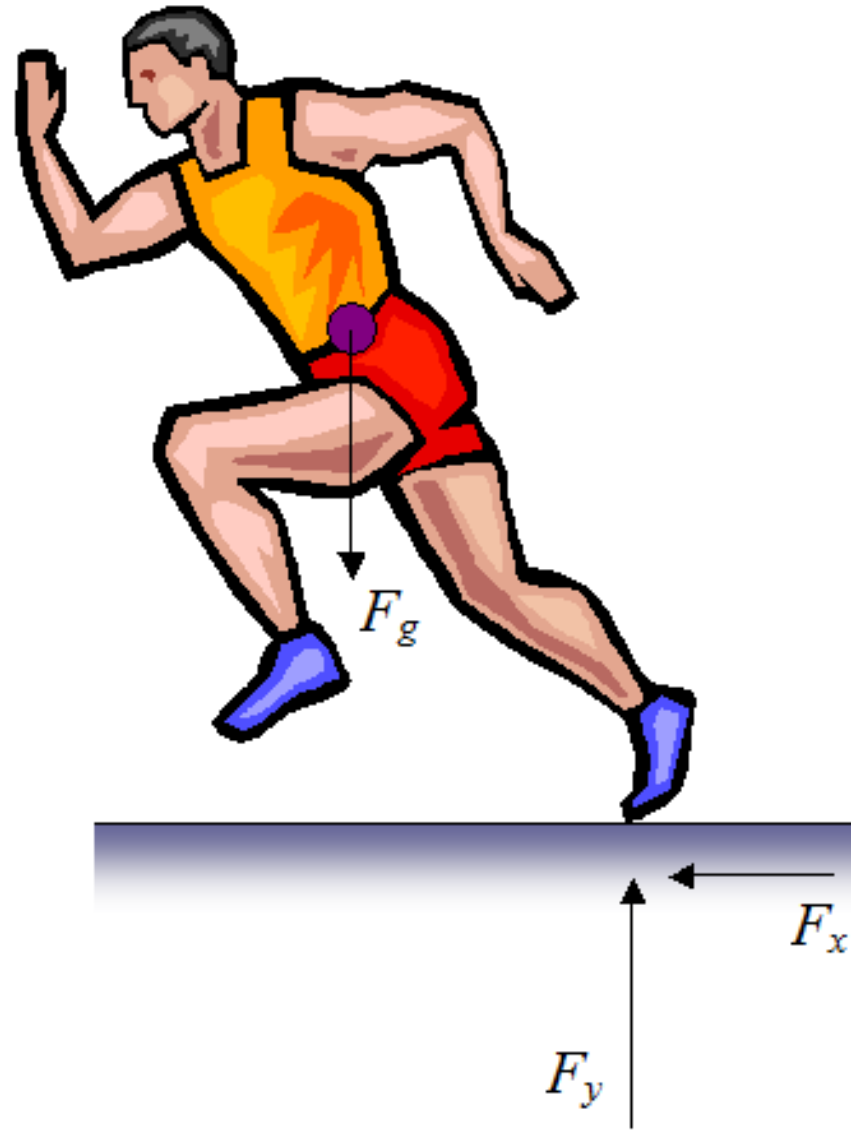
2008	1	Usain Bolt	9.69	
	2	Richard Thompson	9.89	
			0.20	
2009	1	Usain Bolt	9.58	
	2	Tyson Gay	9.71	
			0.13	
2011	1	Yohan Blake	9.92	
	2	Walter Dix	10.08	
		*Usain Bolt DQ	0.16	
2012	1	Usain Bolt	9.63	
	2	Yohan Blake	9.75	
			0.12	
2013	1	Usain Bolt	9.77	
	2	Justin Gatlin	9.85	
			0.08	
2015	1	Usain Bolt	9.79	
	2	Justin Gatlin	9.80	
			0.01	
2016	1	Usain Bolt	9.81	
	2	Justin Gatlin	9.89	
			0.08	
2017	1			
	2			
	?			
<i>Courtesy of SpeedEndurance.com</i>				

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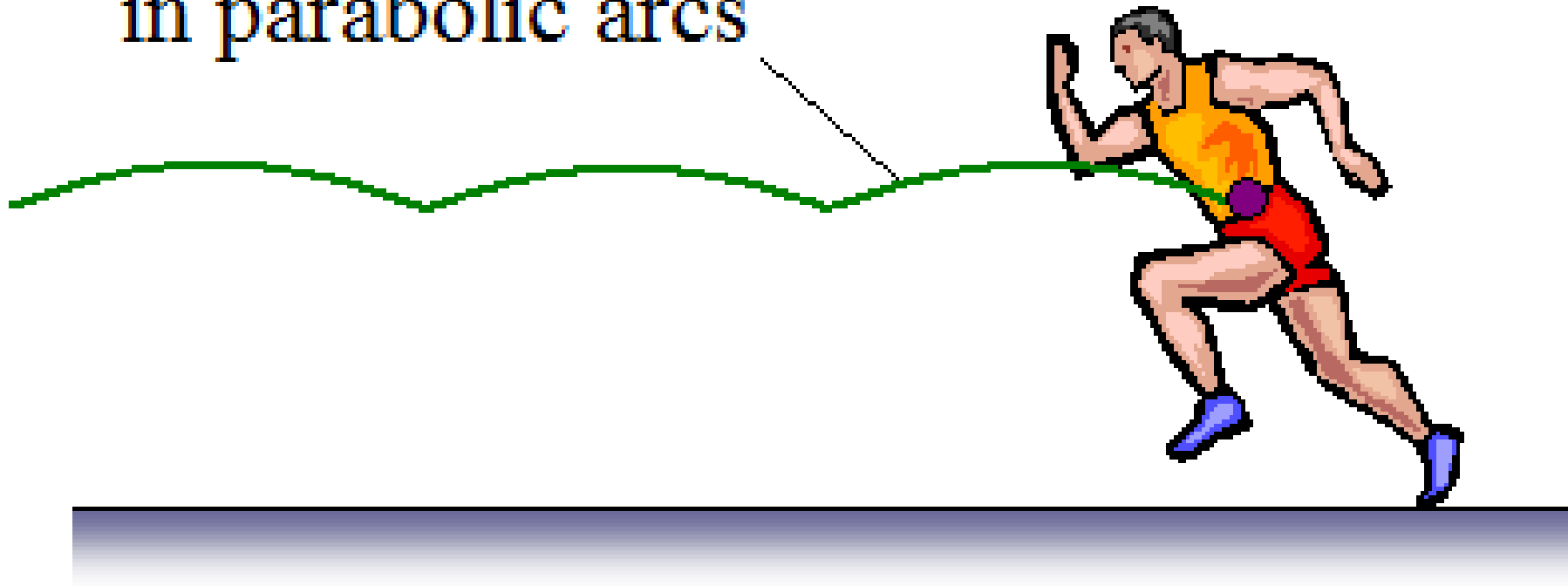


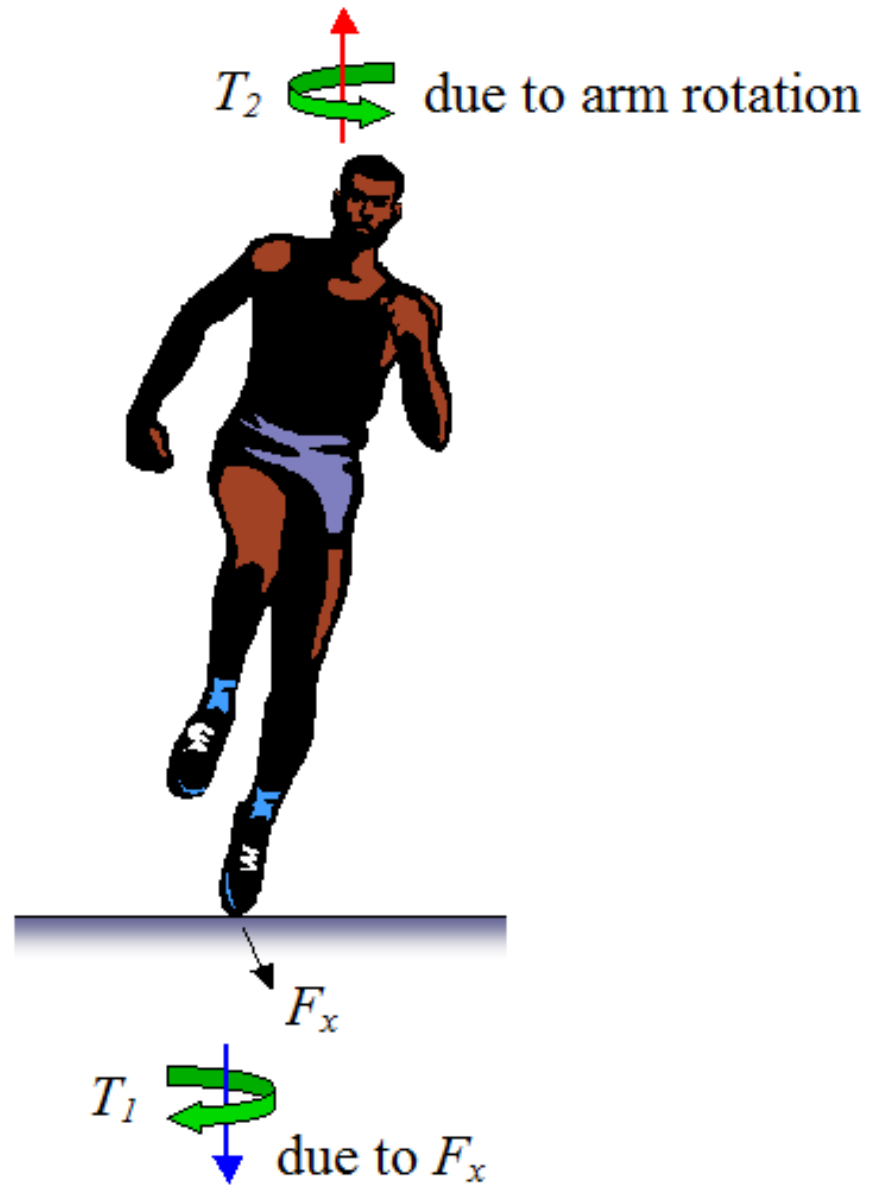
Velocity graphs for Usain Bolt's record-setting 100-m dash. On the left is the “physicist’s style” of plotting velocity versus time; the acceleration is the slope of this curve at any point. On the right is a common graph found in sports newspapers and magazines, of velocity versus distance.

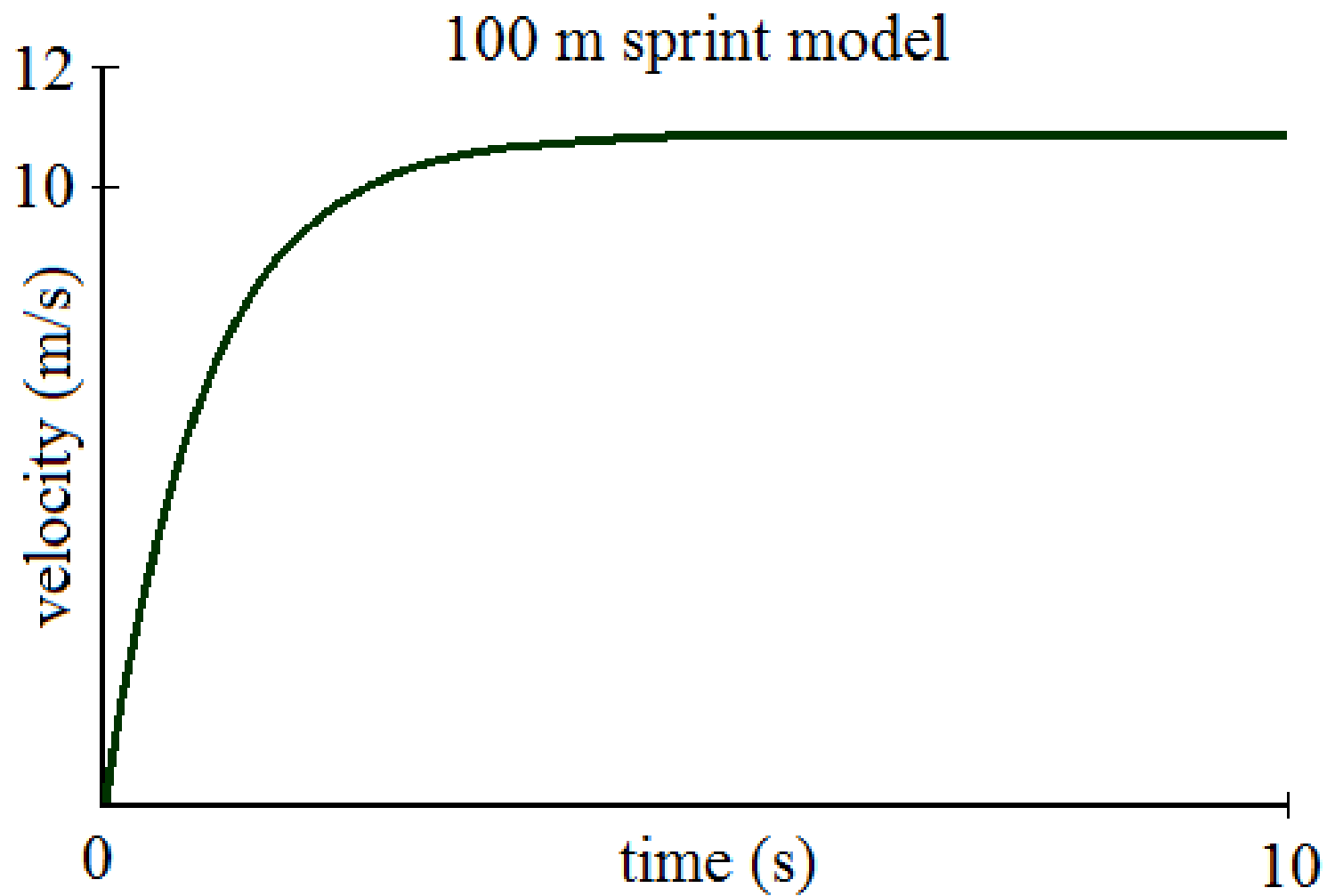
Bolt in Berlin

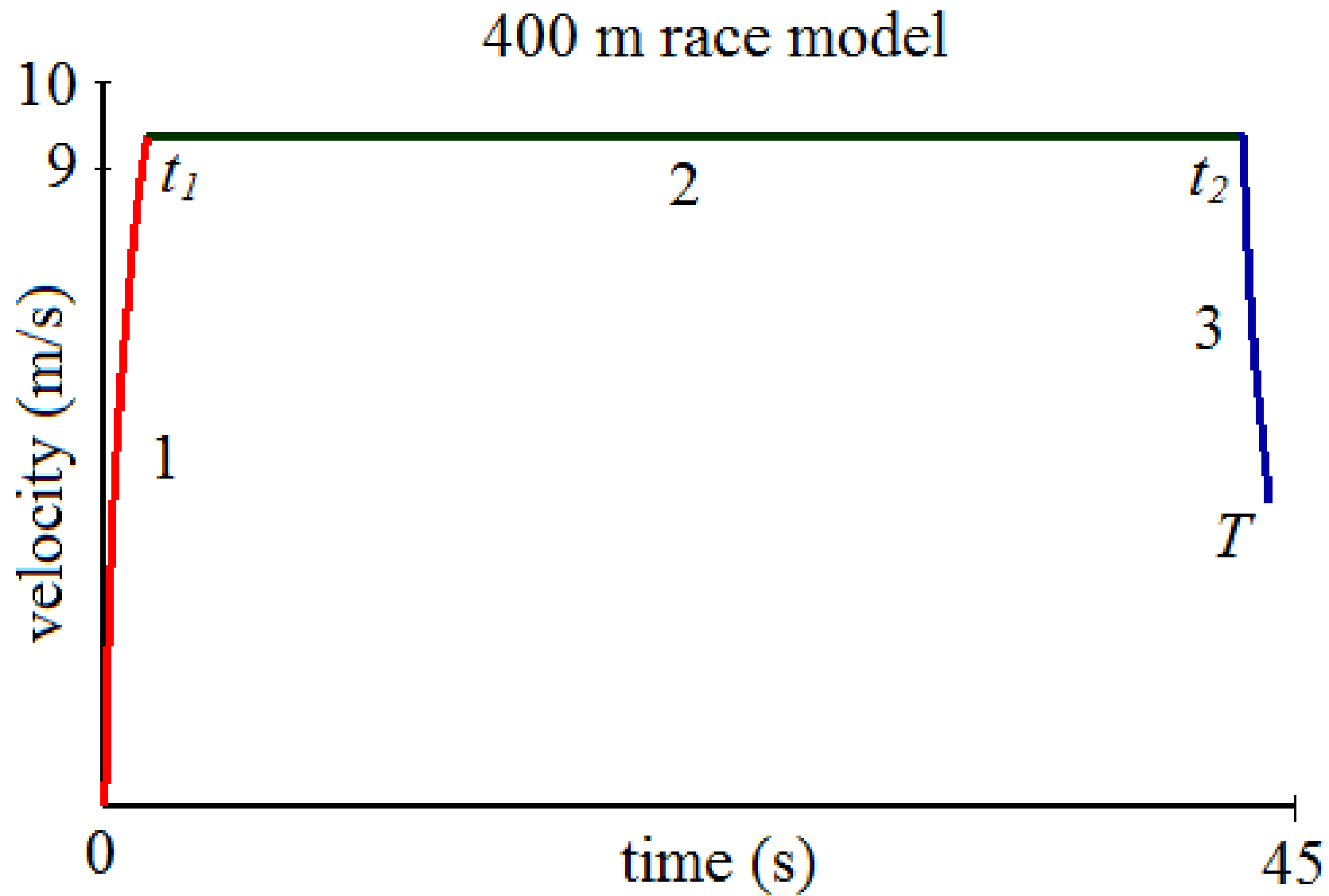


center of mass moves
in parabolic arcs



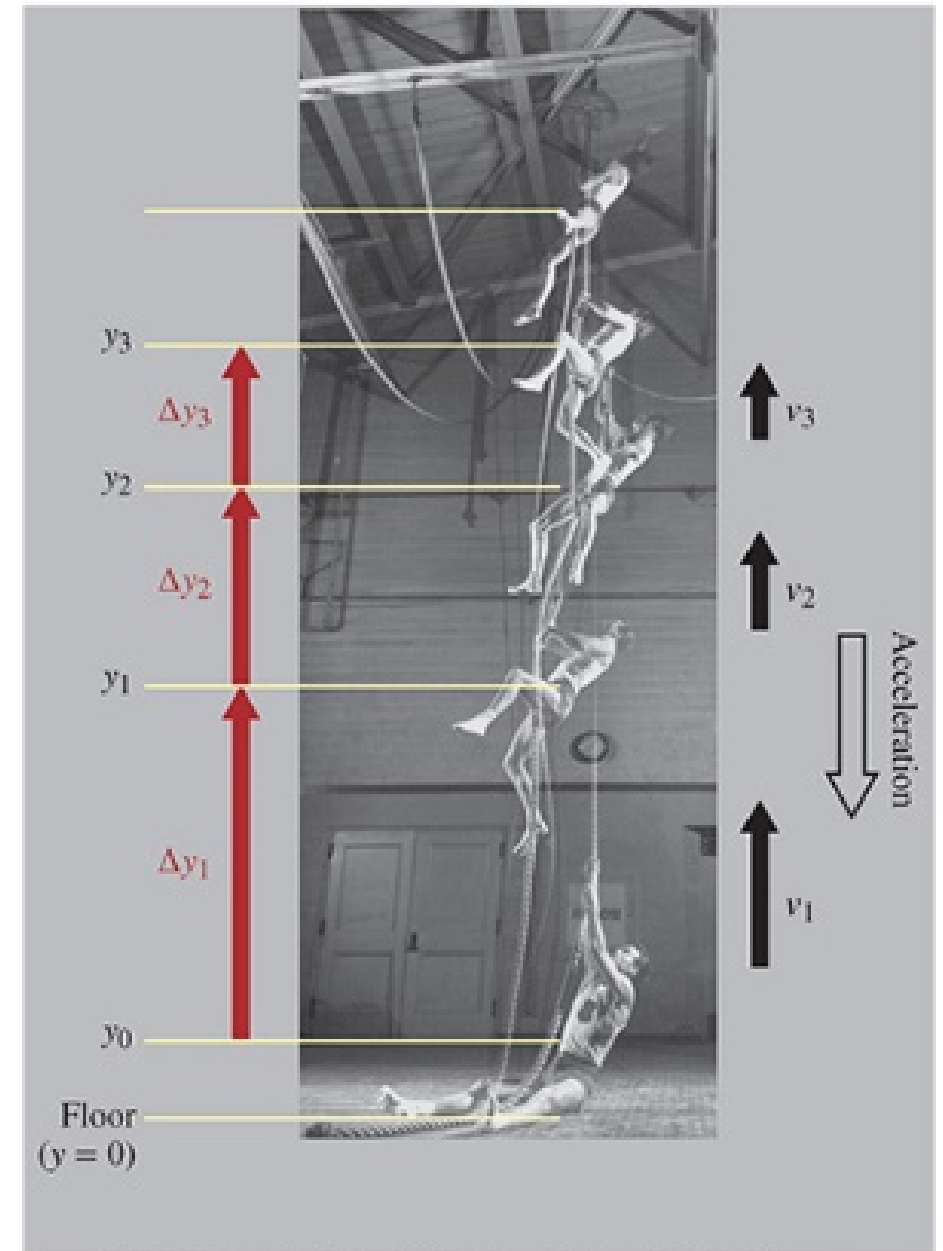


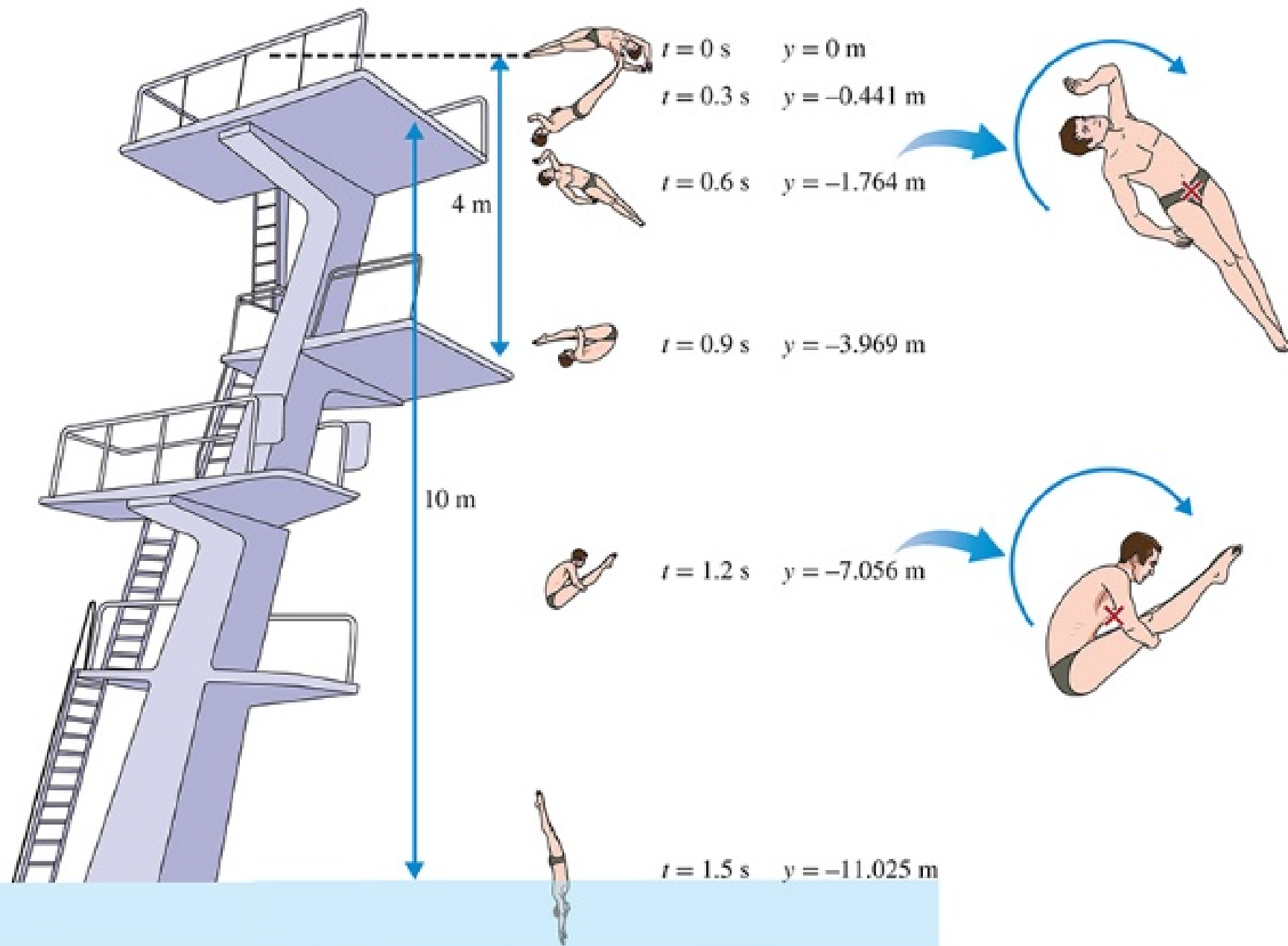




Rope-climbing and diving

Calculate the free fall time from the top, assuming his feet are 13 ft above the ground at that time.







<https://www.pinterest.com/beakymcgee/time-lapse-photos/>

Food for thought

- What is Magnus effect?

References

1. Dan Whitt, *Mathematical Models of Running*, UMS talk, September 24, 2008. <http://www.stanford.edu/~dwhitt/UMS-talk.pdf>
2. Joseph B. Keller, *A Theory of Competitive Running*, *Physics Today* **26(9)**, 42-47 (1973).
3. Igor Alexandrov and Philip Lucht, *Physics of Sprinting*, *American Journal of Physics* **49**, 254-257 (1981).