UNIVERSITY OF LEEDS

Mechanics 1

Session 1 – 1D Kinematics: Distance, Speed & Acceleration

DR BEN HANSON

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First of all...

Welcome to the University of Leeds!

And congratulations on getting here

If you are here, it is because we believe you can do this degree
It is because you deserve to be here

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The Admin Stuff

But it is really important

Who Am I?

Name: Ben Hanson
Field: Computational Biophysics
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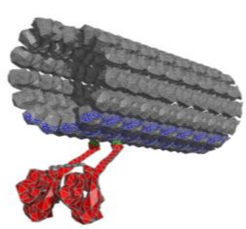
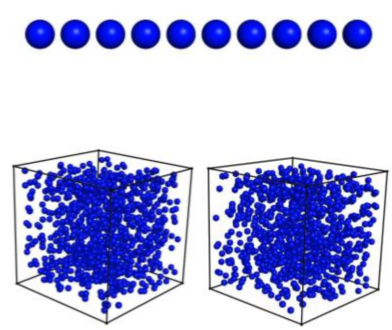
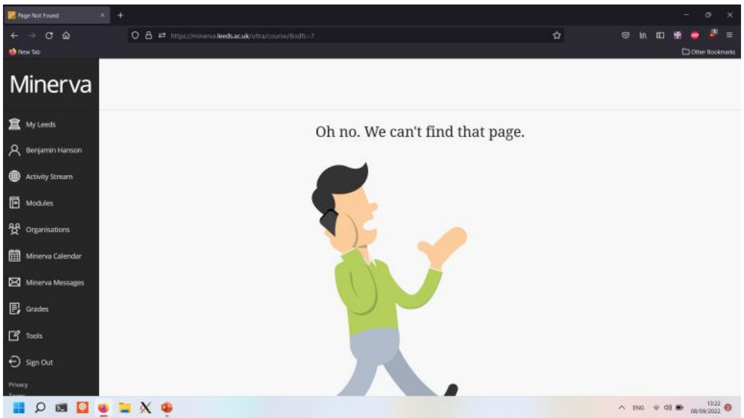
Email: b.s.hanson@leeds.ac.uk





Minerva

What is it?



Who do I email?

- Content issue – Me (b.s.hanson@leeds.ac.uk)
- Technical issue – A friend first, then me, then IT
- Login issue – Turn it off and on again, clear browser cache, then me, then IT

School Support

Who is it?

Academic Stuff:

- Lecture Questions – Lecturer / Module Leader
- Admin Questions – Student Information Service
- Other questions – Academic Personal Tutor

Feel uncomfortable with any of these? Talk to any staff member you want, and they will usually be happy to help ☺

Pastoral Stuff (Life, Mental Health, Support etc):

- Most questions – Student Information Service
- Want someone you know? – Academic Tutor

General Information:

- The desk in the Parkinson building foyer

https://students.leeds.ac.uk/

https://students.leeds.ac.uk/info/10700/support_and_wellbeing/804/helpful_support_contacts

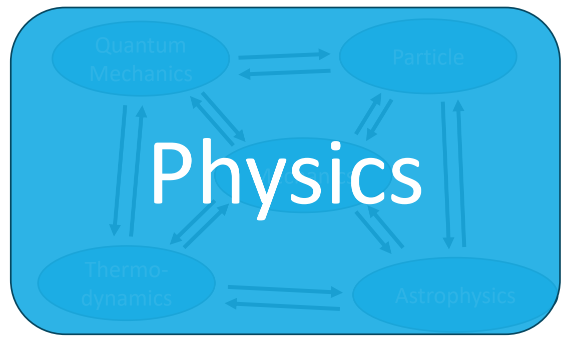
This Module

What do I need to do?

Overview

The Physics & Astronomy Department are implementing a synoptic curriculum

- Up to now, you will likely have experienced a modular structure to your education. Each bit of "learning" comes neatly packaged as an independent chunk.
- In reality, no form of knowledge is so neatly cut. In fact, one can argue that **true intelligence is not the ability to know ideas, but to connect ideas**
- Our curriculum is built to do exactly this. So don't be afraid. **Be excited!**



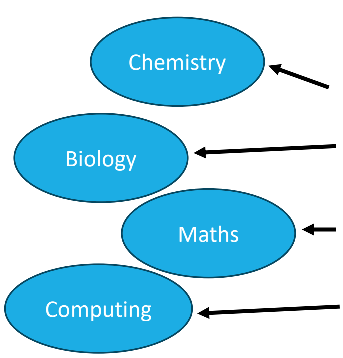
MECHANICS 1 – 1D KINEMATICS

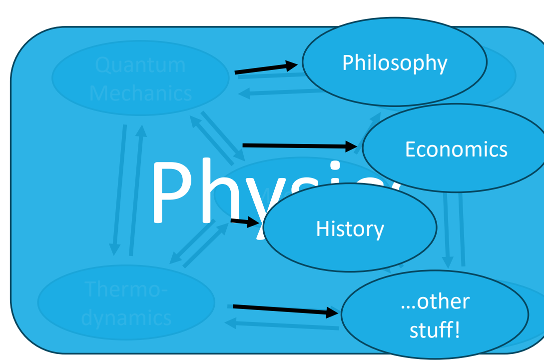
This Module

What do I need to do?

Overview

The Physics & Astronomy Department are implementing a synoptic curriculum





This Module

What do I need to do?

This is the **Mechanics** component of Physics, Year 1

Contact time (Mechanics):

1. Lectures
   - Variable:
     Stick to your timetable!
     Check the mechanics timeline
   - Mandatory! Come to them, interactive lectures are good ☺
2. Workshops
   - Ad-hoc (replacing lectures)
   - Mandatory! Come to them, discussion and problem solving is how you advance learning ☺

Assignments:

1. Homework (40% of total grade)
   - VITALS, assessed by Mobius quizzes
2. Exam (60% of total grade)
   - One exam at the end of the year!
   - Synoptic paper: Questions involving all aspects of physics
   - If you sit the exam, you have already passed the year! Less pressure = better physics ☺

Non-contact time (Mechanics):

1. Read some books!
   - Tipler is good
   - Feynman Lectures on Physics are good
2. Watch some YouTube videos
   - 3Blue1Brown is amazing for maths
   - Some US universities release their undergrad courses for free on YouTube. Good revision material
3. Do some (safe!) experiments
   - Test the things we talk about!
4. Go for a walk! Not even kidding.

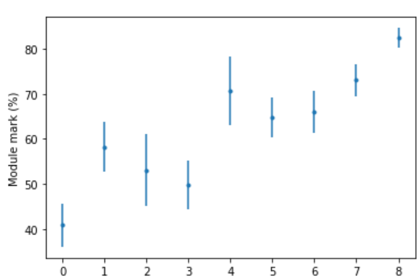
We expect University to be a full working week (i.e. 37.5 hours). Split this however you like.

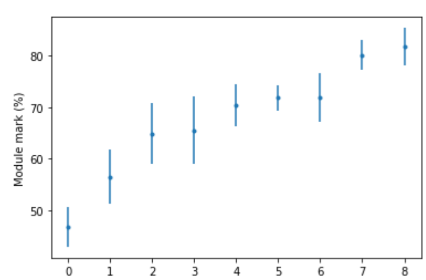
MECHANICS 1 – 1D KINEMATICS

This Module

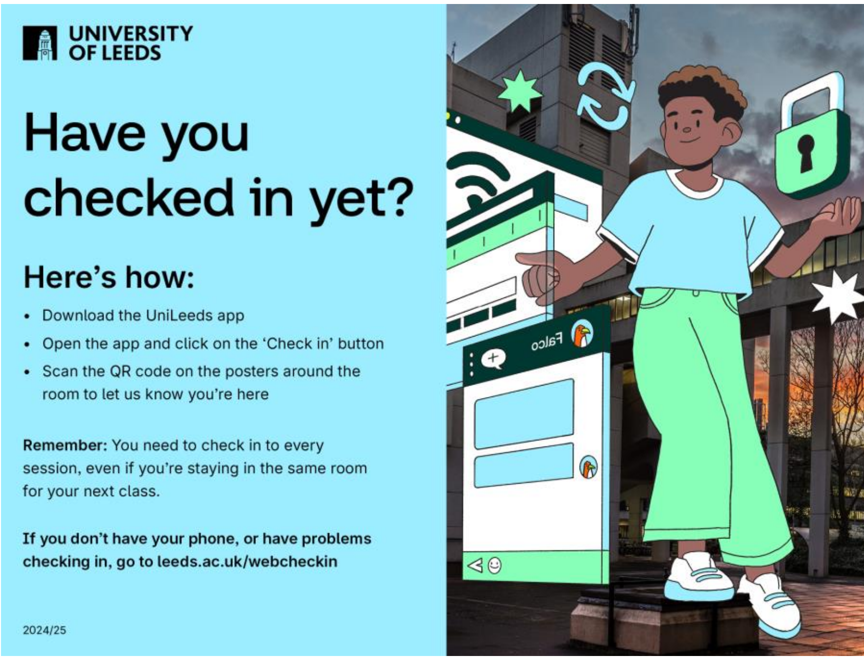
What do I need to do?

Data from Computing 1, 2021





We expect University to be a full working week (i.e. 37.5 hours, 5 days). Split this however you like.



What do I need to do?

The Admin Stuff

But it is pretty important

Done!

Let's do some science

☺

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Mechanics 1

Session 1 – 1D Kinematics: Distance, Speed & Acceleration

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This Lecture

Kinematics

We will learn / recap:

- What mechanics and kinematics are
- The concepts of distance, speed, acceleration, and the links between them

You will be able to:

- Describe what mechanics and kinematics are
- Describe what distance, speed and acceleration are
- Derive the constant-acceleration (SUVAT) equations
- Derive "any" acceleration function from a distance function, or vice versa
- Calculate distances, speeds and accelerations at any future time for a known system

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Mechanics

Mechanics

What is it?

Mechanics is:

- The study of motion
- The beginning of all human knowledge of physics
- The fundamental source of conceptual understanding in physics

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Kinematics

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Kinematics

We are doing physics now!

Kinematics is the study of motion <u>without</u> reference to the causes of motion.

If you think about it, forces, energies, moments, these things are all quite abstract concepts that we just take for granted (what is a force?). So, let's not worry about them just yet! Let's worry about things we can actually see ☺

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Kinematics

We are doing physics now!

Kinematics is the study of motion <u>without</u> reference to the causes of motion.

Physics is about using maths to model very real systems.
So, imagine a real object in motion. Perhaps a car turning a corner, or a person running. A leaf falling.
How might we mathematically describe how it is moving?

Kinematics

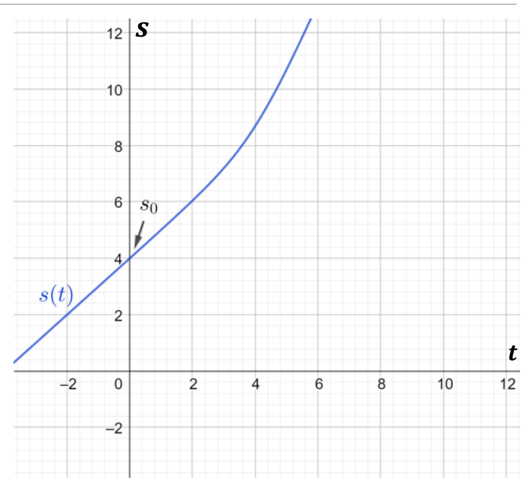
Distance, Speed & Acceleration

Distance Vs Time Graph

Important Things to Notice

- We can define s_0, the "beginning" of motion at time $t = 0s$.
- We can see a speed change at around $t = 4s$
- $v(t) = \frac{ds}{dt}$
- $\int s(t)dt = ?$

This graph is a representation of a real thing. But! it's just a mathematical object that we can analyse using techniques you've all learned already ☺



Kinematics

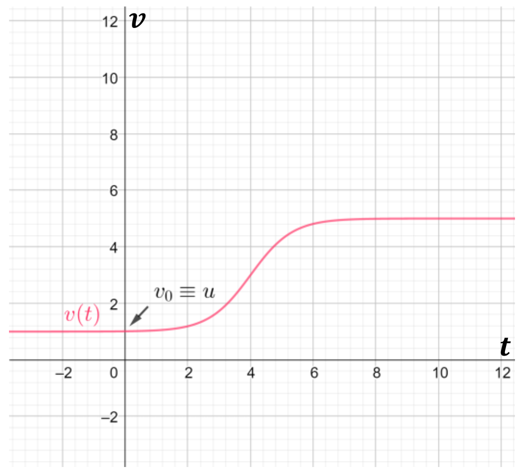
Distance, Speed & Acceleration

Speed Vs Time Graph

Important Things to Notice

- We can define $v_0 \equiv u$, the "beginning" of motion at time $t = 0s$. However, we can no longer see s_0.
- We can see the speed change at around $t = 4s$. We may also notice that there is an acceleration change at around $t = 3s$ and $t = 5s$.
- $a(t) = \frac{dv}{dt}$
- $\int v(t)dt = s(t) + c$

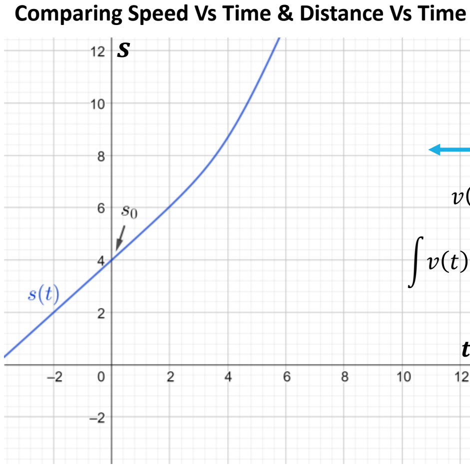
Again, while this represents a real thing, it's just maths!



Kinematics

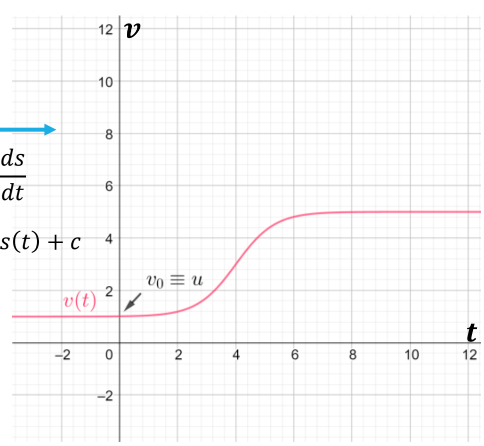
Distance, Speed & Acceleration

Comparing Speed Vs Time & Distance Vs Time



$$v(t) = \frac{ds}{dt}$$

$$\int v(t)dt = s(t) + c$$



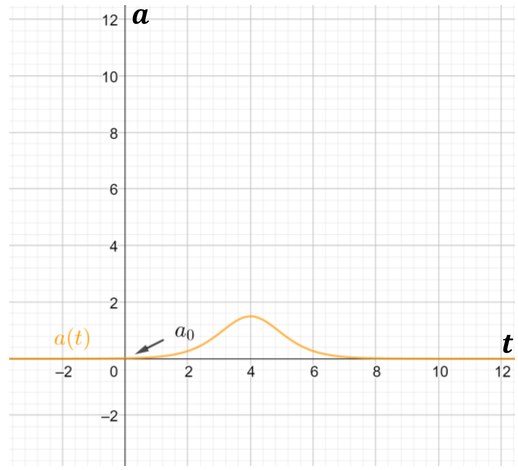
Kinematics

Distance, Speed & Acceleration

Acceleration Vs Time Graph

Important Things to Notice

- We can define a_0, the "beginning" of motion at time $t = 0s$. However, we can no longer see s_0 or v_0.
- We can see the acceleration change at around $t = 3s$ and $t = 5s$. What is beyond this, I wonder?
- $\frac{da}{dt} = ?$
- $\int a(t)dt = v(t) + c$

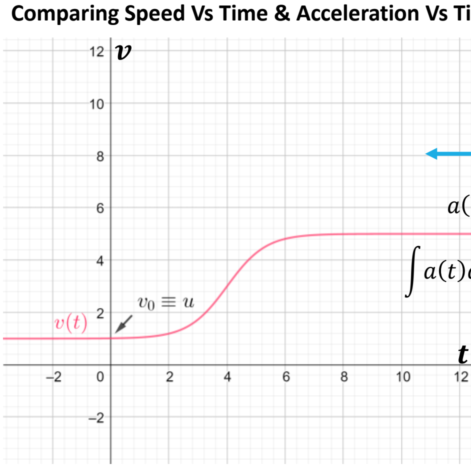


Again, while this represents a real thing. It's just maths!

Kinematics

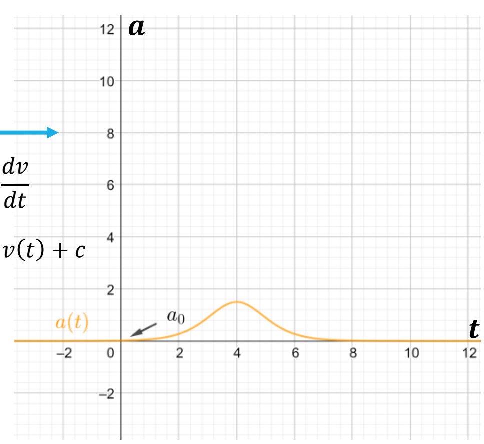
Distance, Speed & Acceleration

Comparing Speed Vs Time & Acceleration Vs Time



$$a(t) = \frac{dv}{dt}$$

$$\int a(t)dt = v(t) + c$$



Kinematics

Jerk (Jolt), Snap (Jounce), Crackle, Pop

We can keep differentiating for as long as we want!

$$v(t) = \frac{ds}{dt}$$

$$a(t) = \frac{dv}{dt} = \frac{d^2s}{dt^2}$$

$$Jerk(t): \frac{da}{dt} = \frac{d^3s}{dt^3}$$

$$Snap(t): \frac{d(Jerk)}{dt} = \frac{d^4s}{dt^4}$$

$$Crackle(t): \frac{d(Snap)}{dt} = \frac{d^5s}{dt^5}$$

$$Pop(t): \frac{d(Crackle)}{dt} = \frac{d^6s}{dt^6}$$

I think jerk is the only important one to know about, as we've all probably felt it in cars. You know when you mess up the gears and stall the car and it wobbles violently and feels weird? That's jerk.

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Constant Acceleration

Equations of Motion

Constant Acceleration

Equations of Motion

All equations involving only acceleration, velocity & displacement are kinematic equations.

Thus, there are many different types of kinematic equation, each applying to a different aspect of physics. Let's look now at perhaps the most common type of kinematic equation we encounter in our daily lives...

Constant Acceleration

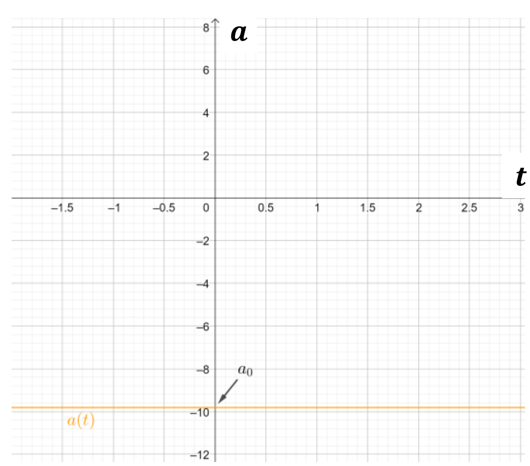
Equations of Motion

Constant Function, $$a(t) = a$$

Differential form, $$\frac{dv}{dt} = a$$

Integral form, $$v(t) = \int a \, dt$$

Integrate, $$v(t) = at + C_1$$



Constant Acceleration

Equations of Motion

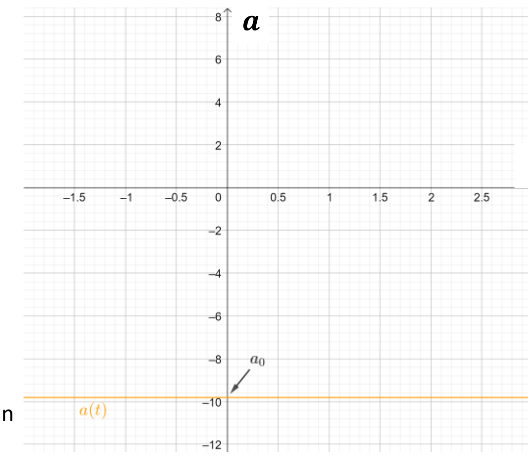
Integrate, $$v(t) = at + C_1$$

Specific conditions, $$Let \quad v(0) = u$$

$$\rightarrow \; u = a.0 + C_1$$
$$C_1 = u$$

Finalise, $$\boxed{v(t) = u + at}$$

Under constant acceleration, speed changes linearly with time from an initial speed u to the speed $v(t)$ at any time t



Constant Acceleration

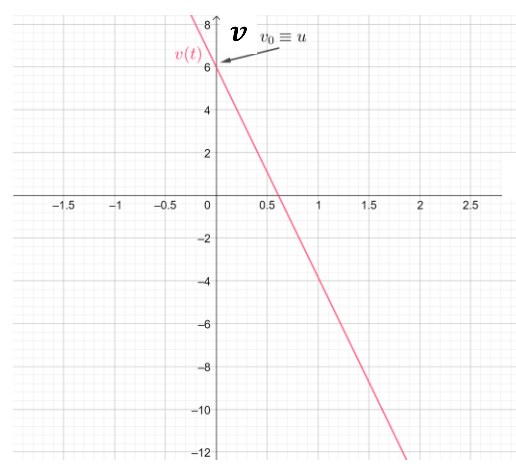
Equations of Motion

Speed Function, $$v(t) = u + at$$

Differential form, $$\frac{ds}{dt} = v(t)$$

Integral form, $$s(t) = \int v(t)\, dt$$

Integrate, $$s(t) = ut + \frac{1}{2}at^2 + C_2$$



Constant Acceleration

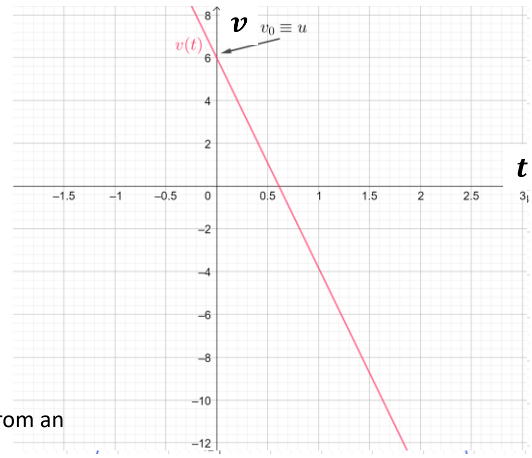
Equations of Motion

Integrate, $$s(t) = ut + \frac{1}{2}at^2 + C_2$$

Specific conditions, $$Let \quad s(0) = s_0$$

$$\rightarrow s_0 = u.0 + \frac{1}{2}a.0^2 + C_2$$
$$C_2 = s_0$$

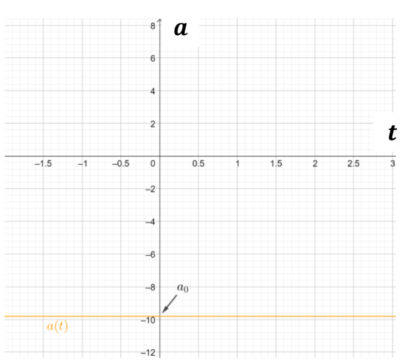
Finalise, $$\boxed{s(t) = s_0 + ut + \frac{1}{2}at^2}$$



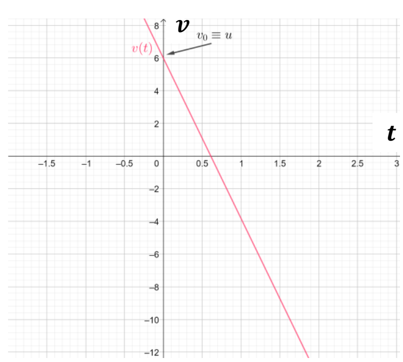
Under constant acceleration, distance changes quadratically with time from an initial position s_0 to the position s(t) at any time t

Constant Acceleration

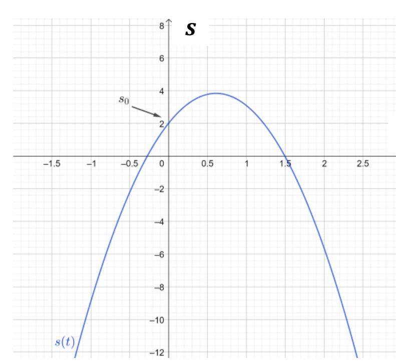
Equations of Motion



$$a(t) = a$$



$$v(t) = u + at$$



$$s(t) = s_0 + ut + \frac{1}{2}at^2$$

Task 1

Deriving the Other Constant Acceleration Equations

Task 1

Deriving the Other Constant Acceleration Equations

Scenario: Using integration, we have derived two equations describing the distance and velocity of a system undergoing constant acceleration:

1. $v = u + at$
2. $s = s_0 + ut + \frac{1}{2}at^2$

Tasks:

1. By eliminating u from the above equations, derive a third constant acceleration equation
2. By eliminating t from the above equations, derive a fourth constant acceleration equation
3. By eliminating a from the above equations, derive a fifth constant acceleration equation

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Non-constant Acceleration

Equations of Motion

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Non-constant Acceleration

Equations of Motion

Example Function (could be anything!),

$$a(t) = At^2 + a_0$$

Differential form,

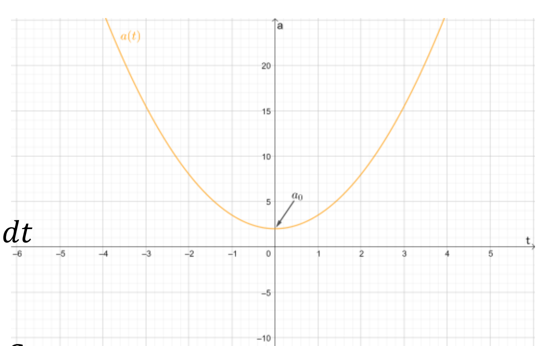
$$\frac{dv}{dt} = At^2 + a_0$$

Integral form,

$$v(t) = \int (At^2 + a_0)\, dt$$

Integrate,

$$v(t) = \frac{A}{3}t^3 + a_0 t + C_1$$



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Non-constant Acceleration

Equations of Motion

Integrate,

$$v(t) = \frac{A}{3}t^3 + a_0 t + C_1$$

Specific conditions,

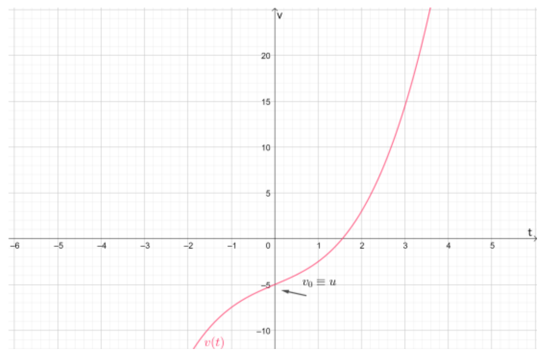
$$Let \quad v(0) = u$$

$$\rightarrow \; u = \frac{A}{3} \cdot 0^3 + a_0 \cdot 0 + C_1$$

$$C_1 = u$$

Finalise,

$$\boxed{v(t) = u + a_0 t + \frac{A}{3}t^3}$$



Non-constant Acceleration

Equations of Motion

Speed Function,

$$v(t) = u + a_0 t + \frac{A}{3}t^3$$

Differential form,

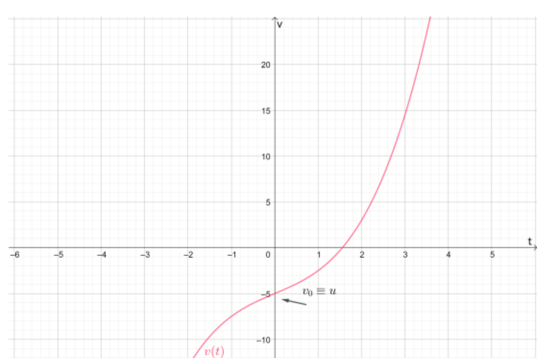
$$\frac{ds}{dt} = v(t)$$

Integral form,

$$s(t) = \int v(t)\, dt$$

Integrate,

$$s(t) = ut + \frac{1}{2}a_0 t^2 + \frac{A}{12}t^4 + C_2$$



Non-constant Acceleration

Equations of Motion

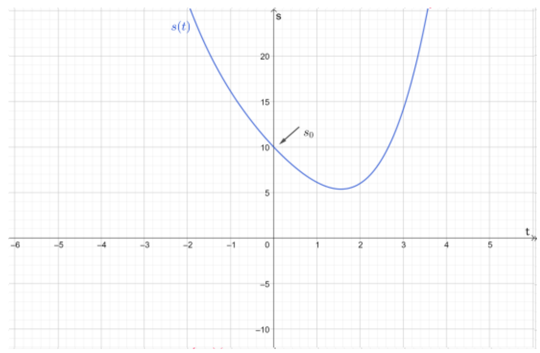
Integrate, $$s(t) = ut + \frac{1}{2}a_0 t^2 + \frac{A}{12}t^4 + C_2$$

Specific conditions, $$Let \quad s(0) = s_0$$

$$\rightarrow s_0 = s(t) = u \cdot 0 + \frac{1}{2}a_0 \cdot 0^2 + \frac{A}{12} \cdot 0^4 + C_2$$

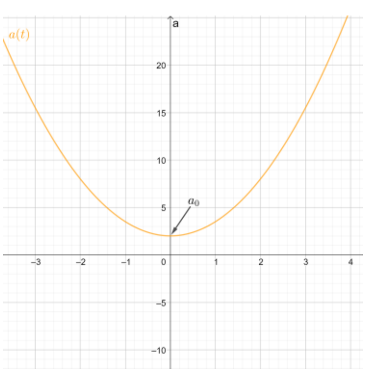
$$C_2 = s_0$$

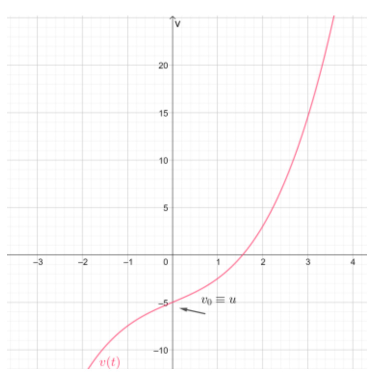
Finalise, $$\boxed{s(t) = s_0 + ut + \frac{1}{2}a_0 t^2 + \frac{A}{12}t^4}$$

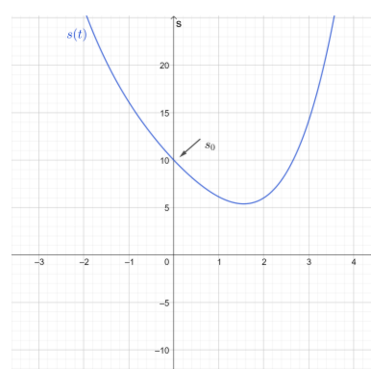


Non-constant Acceleration

Equations of Motion







$$a(t) = At^2 + a_0$$

$$v(t) = u + a_0 t + \frac{A}{3}t^3$$

$$s(t) = s_0 + ut + \frac{1}{2}a_0 t^2 + \frac{A}{12}t^4$$

Task 2

Possible Kinematic Equations

Task 2

Possible Kinematic Equations

Scenario:

Thrown objects are just one form of kinematic equation (constant downwards acceleration, nothing else added). Many others appear all throughout physics!

Tasks:

1. Obtain the speed and acceleration functions, and sketch the graphs, of the following distance functions:
    1. $s(t) = A\cos(\omega t)$ *(pick any values for A and ω that you like)*
    2. $s(t) = Be^{\frac{t}{\tau}}$ *(pick any values for B and τ that you like)*
2. For 1.1, suggest some physical systems that may correspond to these equations of motion
3. For 1.2, is there any physical system that exists that can *permanently* correspond to these equations of motion? How about if there was a negative sign in the exponential?

    Hint: Consider the growth in kinetic energy $E(t) = \frac{1}{2}mv(t)^2$, or perhaps something you know about the speed of light and relativity.