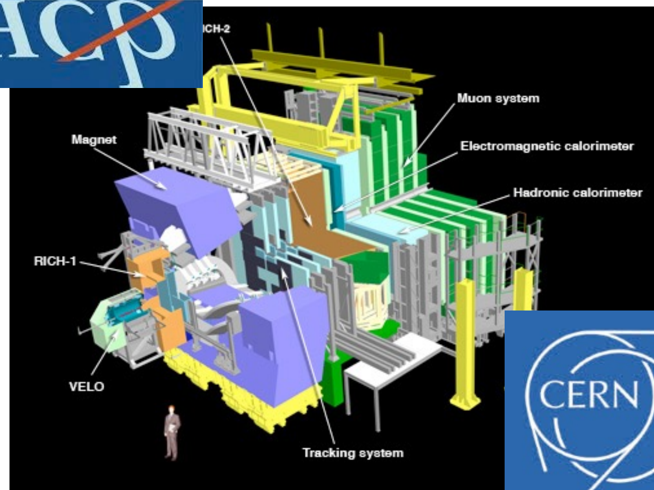
Year 1 – Relativity
Lecture 1

Mitesh Patel

Who am I?

- Lecturer in the High Energy Physics (HEP) group
- Regularly have to deal with relativistic effects!
- Research based at the LHCb experiment at CERN's Large Hadron Collider



Course aims

- The main aims are:
  - To understand Einstein's postulates, and their implications
  - To be able to apply the Lorentz transformation equations
  - To be able to use space-time diagrams and understand the basic properties of four-vectors
  - To be able to apply relativistic energy and momentum to particle collisions

- See the module outline on Blackboard for the full list of topics to be covered

Basic organisation

- The main part of the course is 10 lectures
  - I will try and do chalk-and-talk mixed with slides [technical challenge!]
  - There will be some Menti questions – suggest you think about these as if you were in the lecture theatre [codes separately!]
  - Lecture notes are on Blackboard, but may be updated slightly during the course when I find the inevitable typos [let me know of mistakes!]
  - The notes may contain a bit more detail than the lectures

- I would recommend...
  - Reading quickly through the Blackboard notes just before the lecture; these are usually only ~3-4 pages
  - Taking notes during the lecture to ensure you keep engaged
  - Reread the Blackboard notes after the lecture the same day

Course problem sheets

- Problem sheets will be available every week for the next four weeks
  - Each problem sheet covers material from the lectures of the week
  - They will also be available on Blackboard

- Each problem sheet will have
  - A problem for discussion in tutorials
  - The rest of the questions are for you to do in your own time

- Solutions will be released after the tutorials for that week have finished
  - I do not want to release solutions until you have had to think about the problems without any solutions in front of you

Broader structure of the module

- As well as lectures & problem sheets
  - two seminars to try and help reinforce your understanding:
    - w/c Monday 22nd May
    - w/c Monday 5th June

Important to try and keep up in order to get the most from these

- Assessed components:
  - Problem sheet (5% of M&R module)
    - Released Friday 2nd June, due Friday 9th June
  - Python-based homework (7.5% of M&R module)
    - Released Friday 9th June, due Friday 30th June

Acknowledgements

- Source of much of the course materials: Dr Caroline Clewley and Prof Paul Dauncey, who gave this course the years before I took it over
  - I will not add their names to all notes, problem sheets, etc. but it should be understood that their input was essential for many aspects of the course
  - Any mistakes are of course entirely my own!
  - Bit worried that they might both have had something seriously against small animals…

Office hours

- There are office hours during Weeks 3-5 inclusive
  - Will announce timing once am confident of your final timetable
- These are for discussing items from the lectures
  - Clarifications, concepts, etc.
  - Not really for problem sheets; they are to be worked on in tutorials or discussed with your tutor, and solutions will be available

Recommended books

- I recommend you get hold of either one of the following
  - **Young and Freedman**, *University Physics* (14th edition): This has the main points in one chapter
  - **Martin McCall**, *Classical Mechanics, a Modern Introduction* (2nd edition): This contains two chapters on special relativity which are about the right level for this course
- Both are stocked by the Imperial library
  - I will flag up the relevant sections in each set of lecture notes
  - Beware of differing conventions with the symbols!

Overview of lectures

- Lecture 1: Introduction, concepts and classical results
- Lecture 2: The postulates of Relativity
- Lecture 3: Length contraction and simultaneity
- Lecture 4: The Lorentz transformations
- Lecture 5: Space-time diagrams and world lines
- Lecture 6: Four-vectors and causality
- Lecture 7: Energy and momentum
- Lecture 8: Rest mass energy and particle decays
- Lecture 9: Particle reactions
- Lecture 10: The relativistic Doppler effect

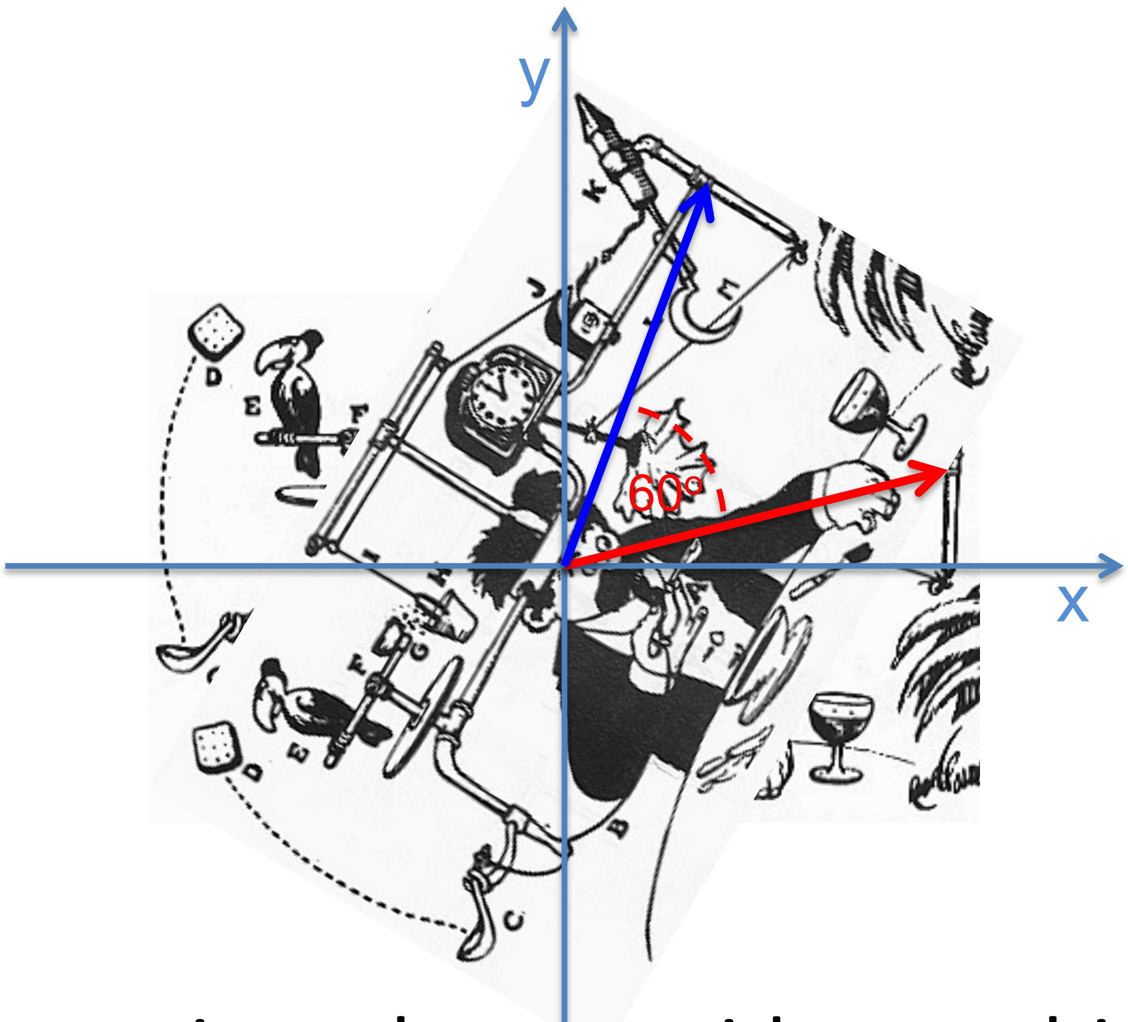
What’s in a name?

- Einstein published the “Theory of Relativity” in 1905
  - It concerned how physical systems appear when moving at (constant) velocities
  - He showed only relative motion was meaningful
- Einstein extended this in 1916 to accelerations
  - The extended theory turned out to be the theory of gravity
- The names have changed to reflect this
  - The first theory is a special case of the second, so the constant velocity theory is now called “Special Relativity”
  - The more general case is called “General Relativity”
- We will cover only Special Relativity (**SR**) in this course

What we will do today

- Understand the concepts of active and passive transformations of coordinates
  - Using the example of rotations
- Understand that if there is a symmetry:
  - Physical laws must hold in any coordinate system
  - We cannot define an “absolute” coordinate system
- Look at the Galilean transformations
  - Classically = pre-Relativity, how coordinates change when an observer is moving
  - Requires observers to be in “inertial frames”

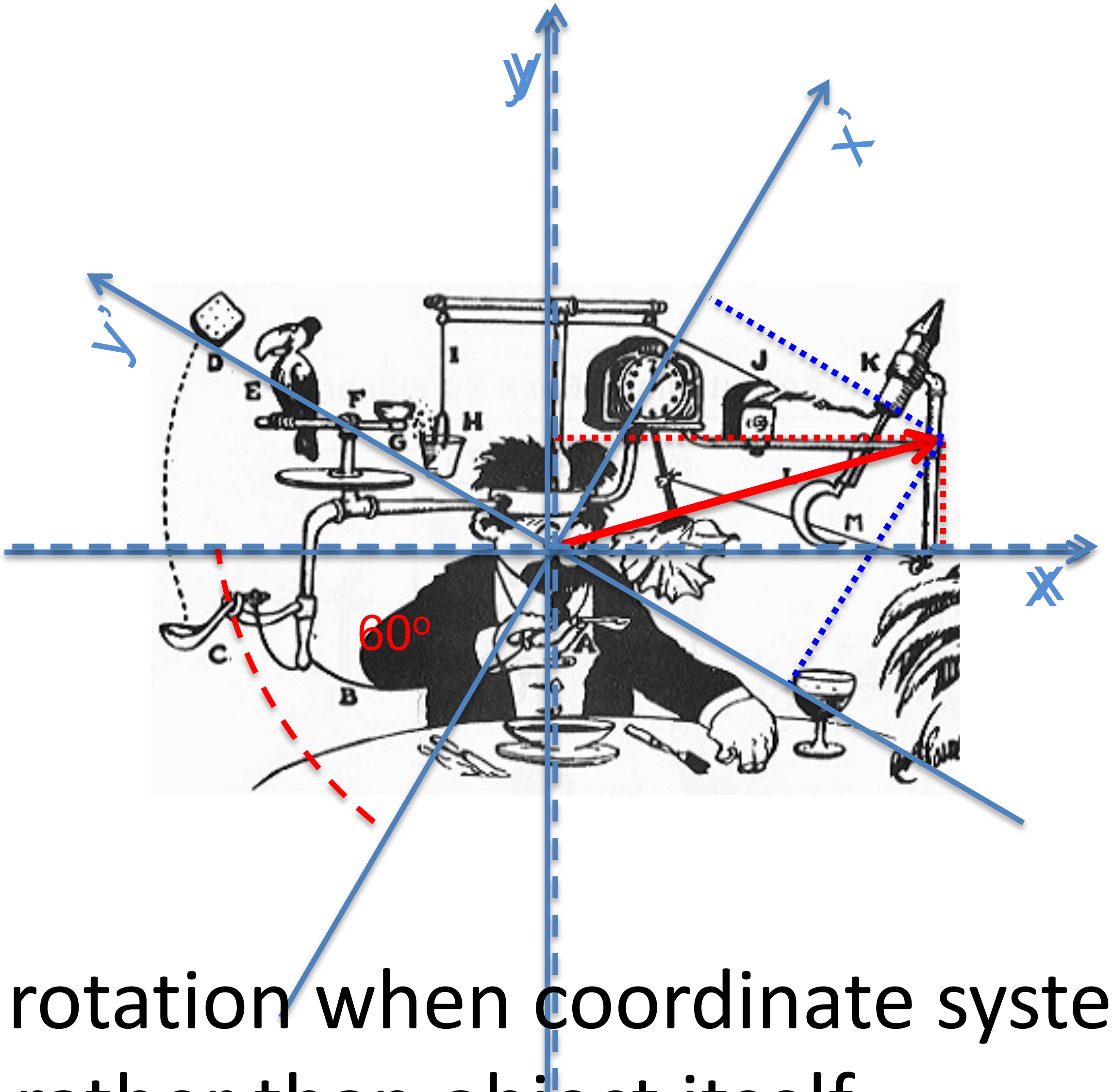
Active rotations



- Active rotation when consider an object to be rotated in a fixed coordinate system

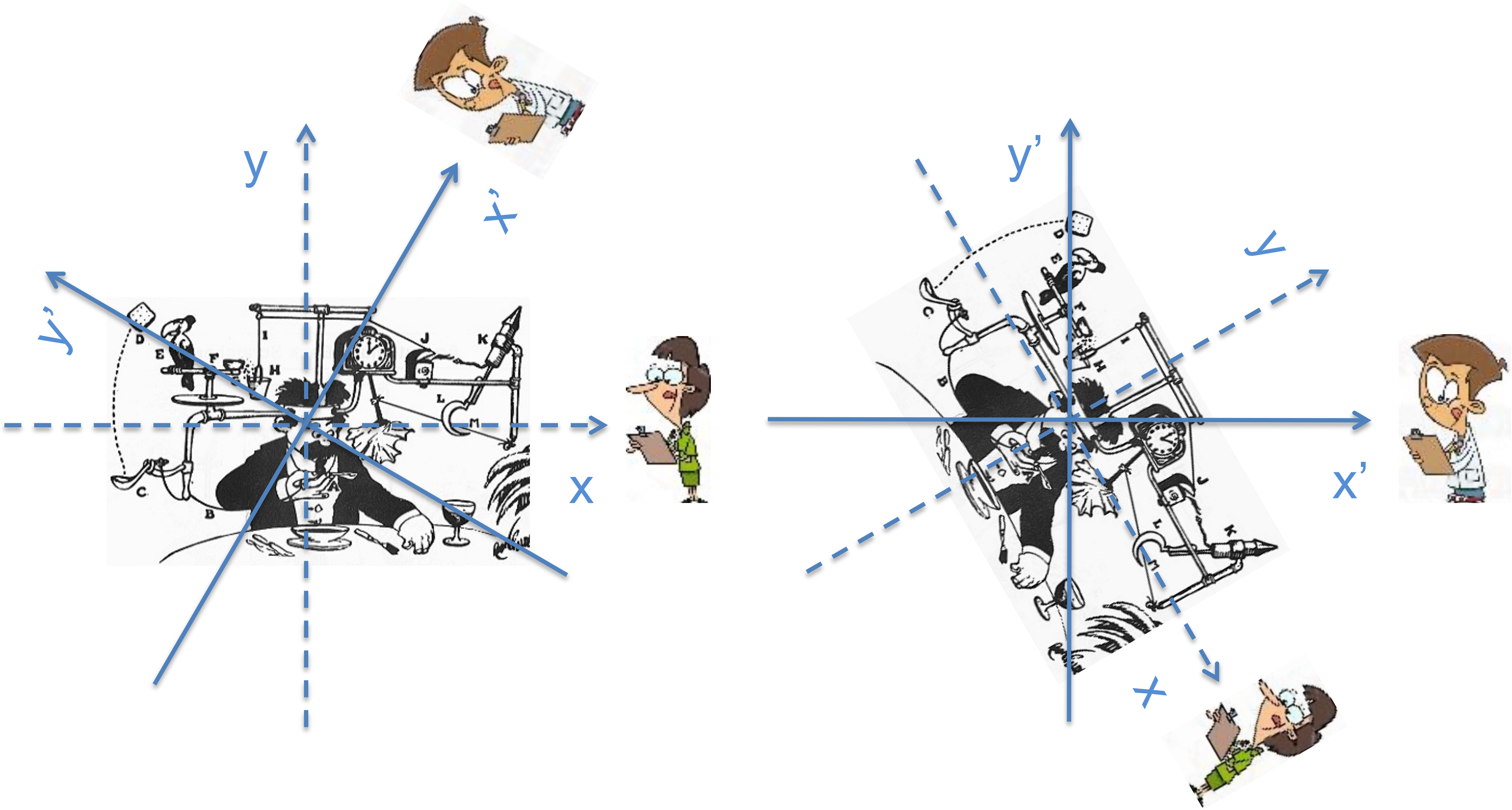
Active rotations

Passive rotations



- Passive rotation when coordinate system rotated rather than object itself

Active vs Passive observers



- Passive rotation by angle ϕ mathematically equivalent to active rotation by angle $-\phi$

Passive rotations

Comparing experiments

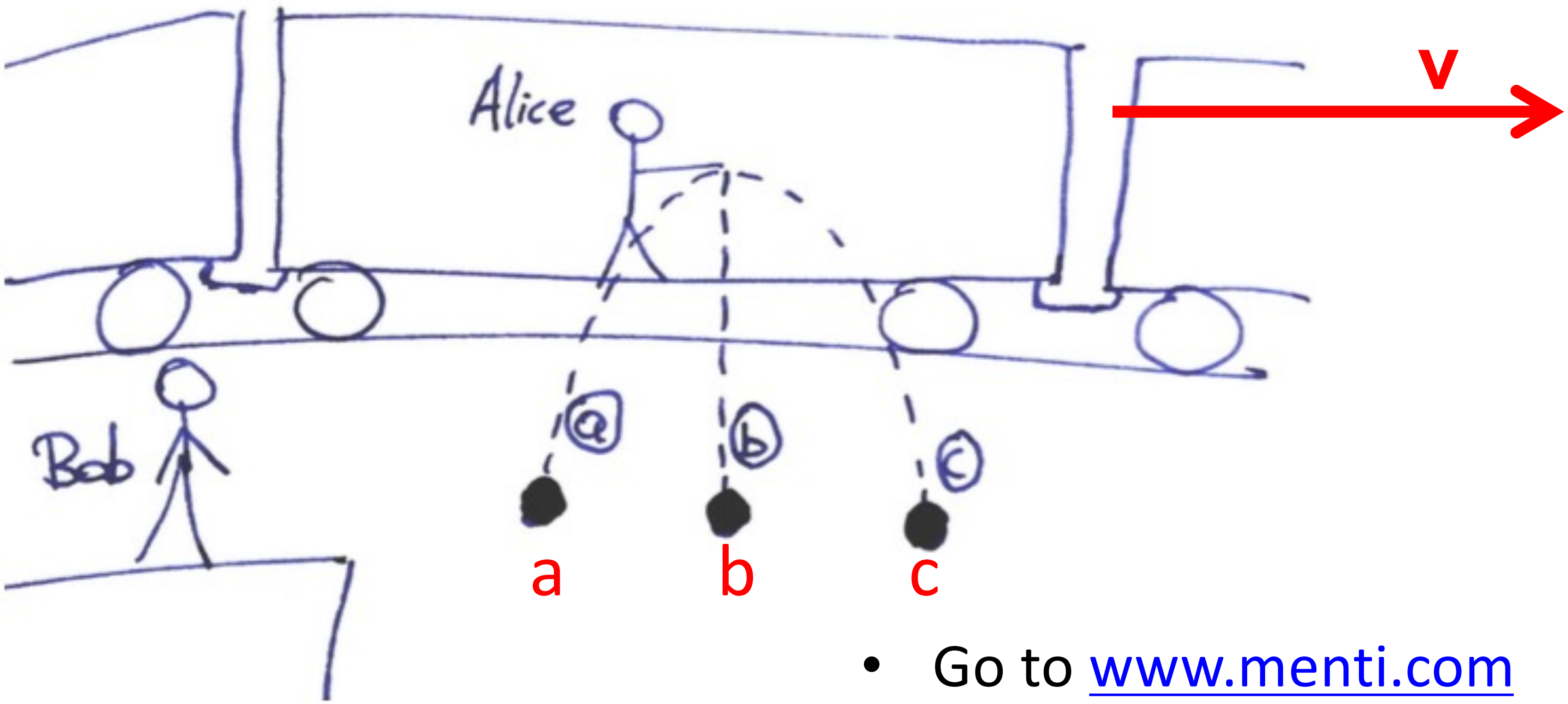
- Active observer
  - The observer watches an experiment
  - All the apparatus is rotated by some angle $-\phi$
  - The experiment is repeated
  - If physical motion doesn't change the apparatus, the observer should see the same results
- Passive observers
  - Two observers use different coordinate frames rotated by ϕ
  - The experiment is done once
  - The two observers will see the same results

Rotations and symmetry

- Fundamental assumption of physics that space is ‘isotropic’
  - Space is the same in all orientations and has no ‘special’ direction
- Another way of stating this,
  - We believe there is a perfect symmetry in all directions of space
  - If physical laws are valid in all frames, then which coordinate frame to use is arbitrary. Any frame is as good as any other frame; no coordinate frame is ‘better’ than the others

Classical physics

- Alice is standing in a train moving with constant speed v relative to Bob on the platform
  - As she passes Bob, Alice drops a ball out of the window.



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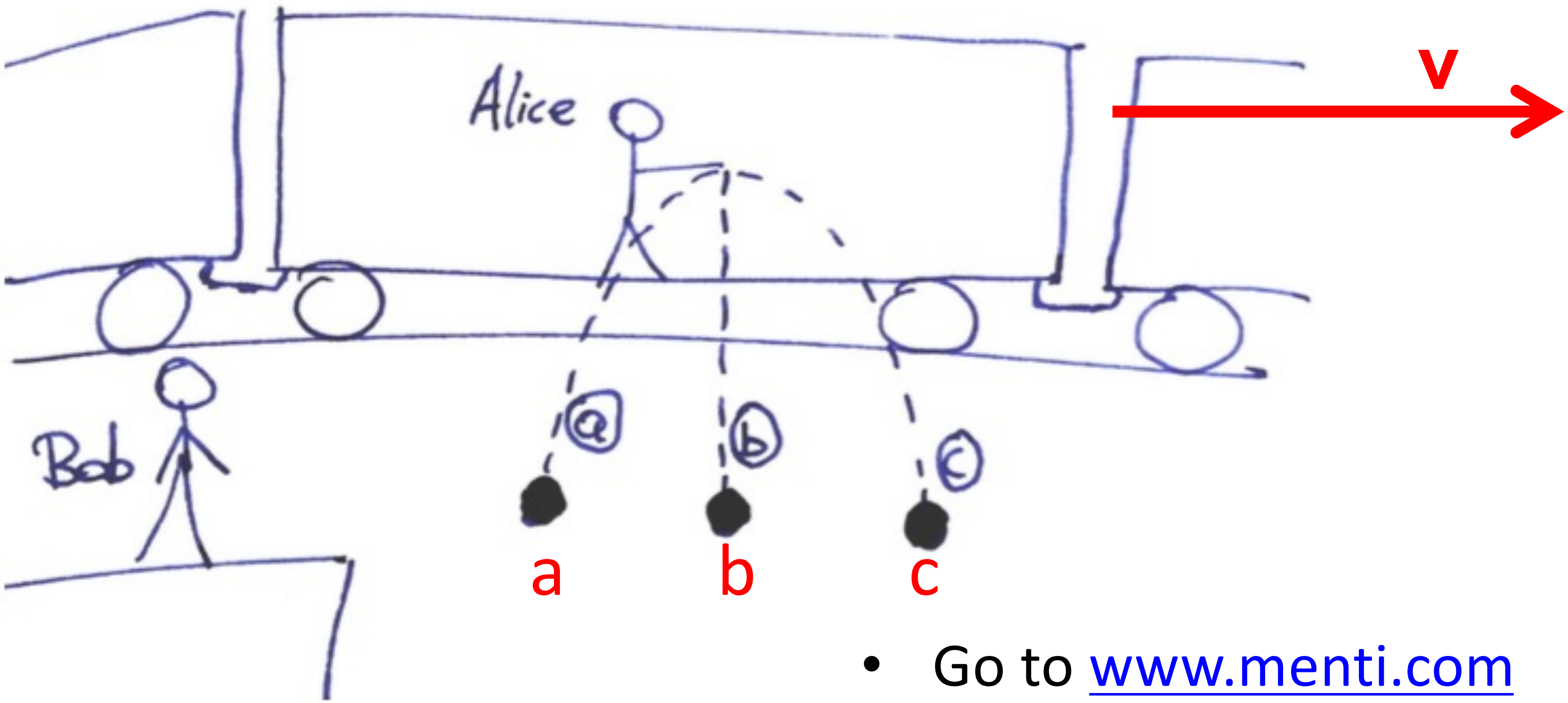
Classical physics

- Ignoring air resistance
  - Question 1: which path of the ball does Alice observe?
  - Question 2: which path of the ball does Bob observe?



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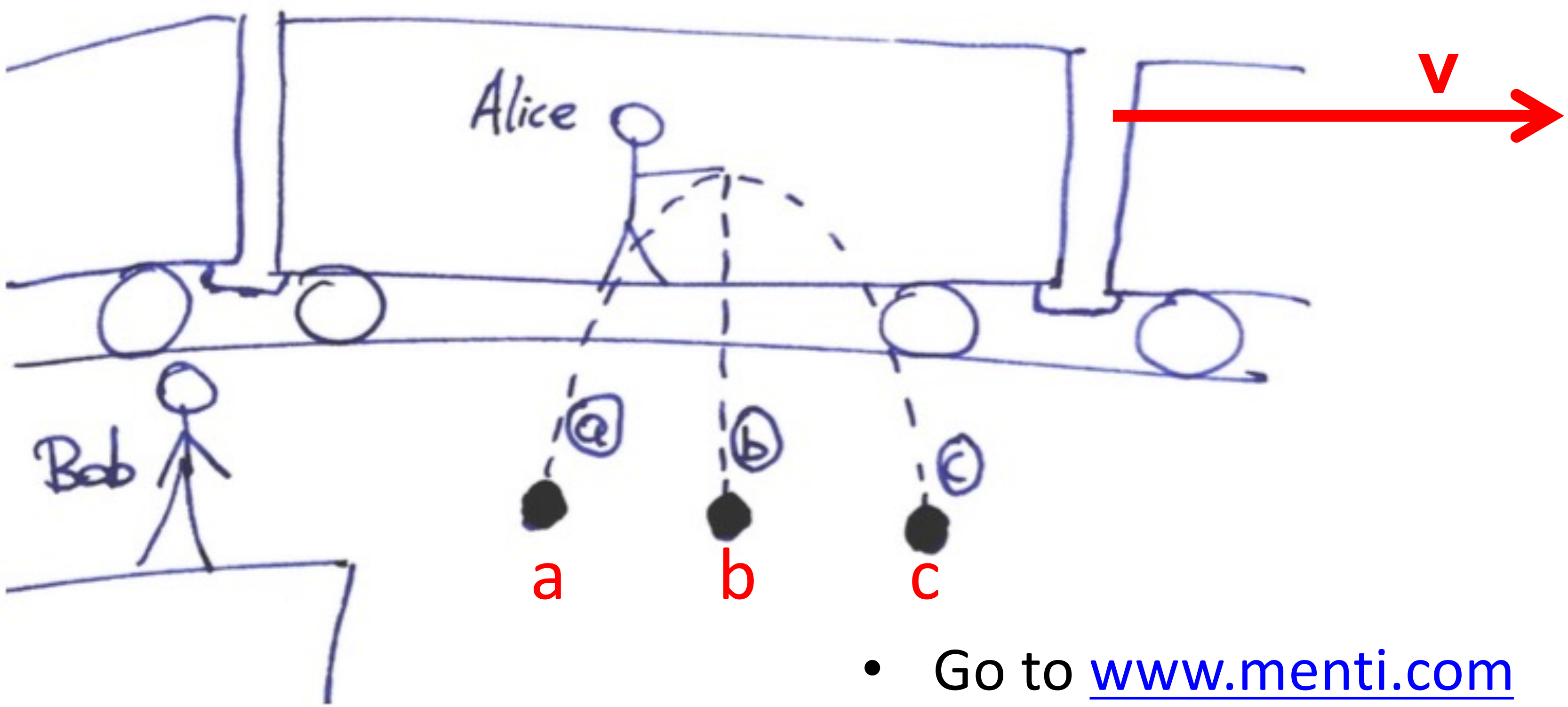
Classical physics

- Given that there is only one set of Newton's laws
  - Question 3: Who sees the ball obey Newton's laws?
  - Alice, Bob, both or neither?



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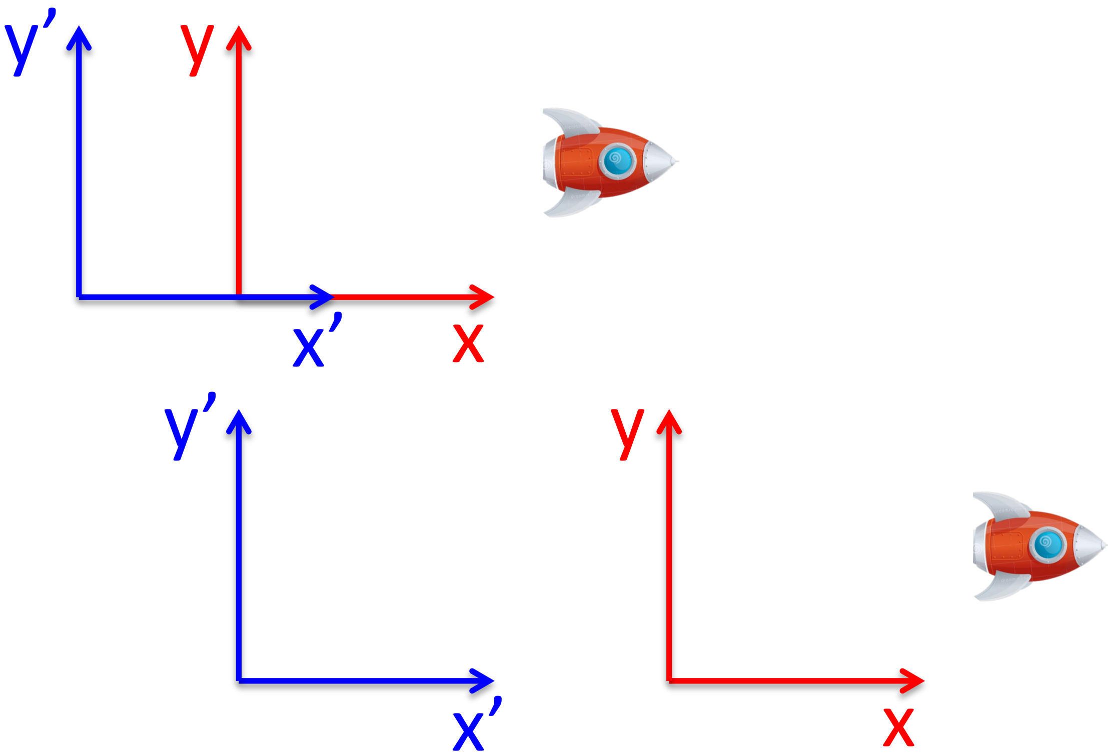
Relativity and transformations

- Fundamental concept underlying Relativity which is equivalent to the rotational symmetry
  - all physical laws must be valid when transforming from one coordinate frame to another
- In SR, the transformation is not due to a change of angle, but to a change in velocity
  - Transformation is mathematically similar to the rotations we saw earlier
  - SR is the special case of frames moving only with fixed velocities, called ‘inertial frames’

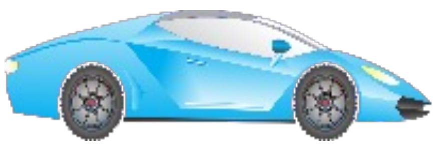
Inertial frames

- A frame in which any body remains at rest or moves with constant velocity unless acted upon by forces
- Any other frame moving with constant velocity relative to an inertial frame is also an inertial frame.

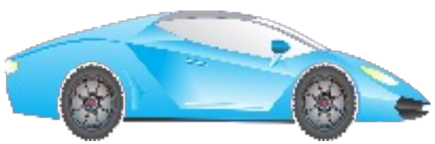


Relative motion

- Rashid is a traffic cop at Rest by a motorway
- Sam is Sensible and sticks to the Speed limit of 70 mph
- Beth is Breaking the speed limit, doing 90 mph

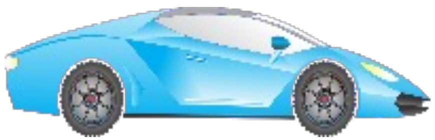


What does Sam observe?



- Rashid is going at –70 mph (i.e. to the left)
- Sam is at rest
- Beth is doing 20 mph

What does Beth observe?

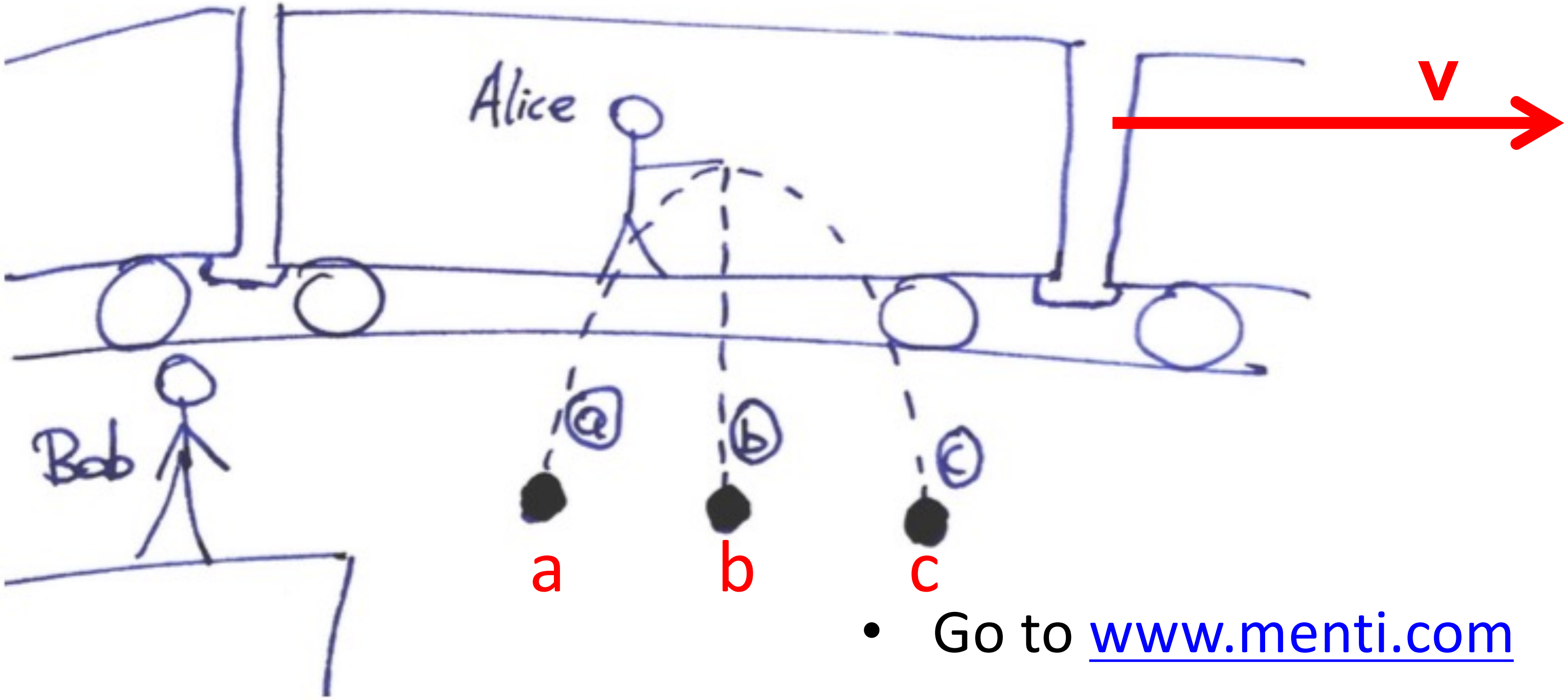


- Rashid is going at −90 mph
- Sam is going at −20 mph
- Beth is at rest

Galilean transformations

The road ahead

- Imagine Alice throws the ball in the direction of travel, with velocity u
- Question 1: What horizontal speed will Bob observe?
- Question 2: What if u=c?



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Galilean transformations vs rotations

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