

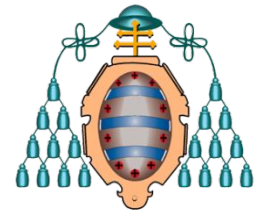
Teaching Classical Mechanics with Smartphones: acceleration and trajectory

María Vélez
Physics Department



Real
Sociedad
Española de
Física

R.S.E.F.



UNIVERSIDAD DE OVIEDO

Universidad de Oviedo

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Jaime Ferrer

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María del Rosario Díaz

Crespo

Isidro González Caballero

Javier Fernández

Departamento de Informática

Susana Irene Díaz María

Rita Sierra

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High School

IES Valle de Aller

María Luisa Amieva

Consejería Educación

María Luisa del Valle

IES Aramo

**M^a Fernanda Fernandez
Varela**

Real Sociedad Española de Física

Sección Asturias

Jorge Pisonero

Victor García

Physics and Math (1st University year)
Physics Olympiad (final high school year)

2016/2017

2017/2018

2018/2019

Basic Mechanics Theory Course: *Simple kinematics examples*

Constant Speed

$$a = 0$$

$$v = v_0$$

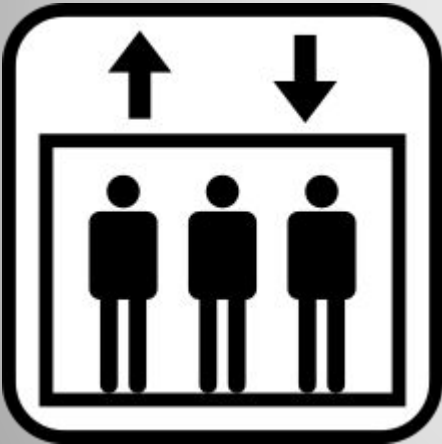
$$x = x_0 + v_0 * t$$

Constant acceleration

$$a = a_0$$

$$v = v_0 + a_0 * t$$

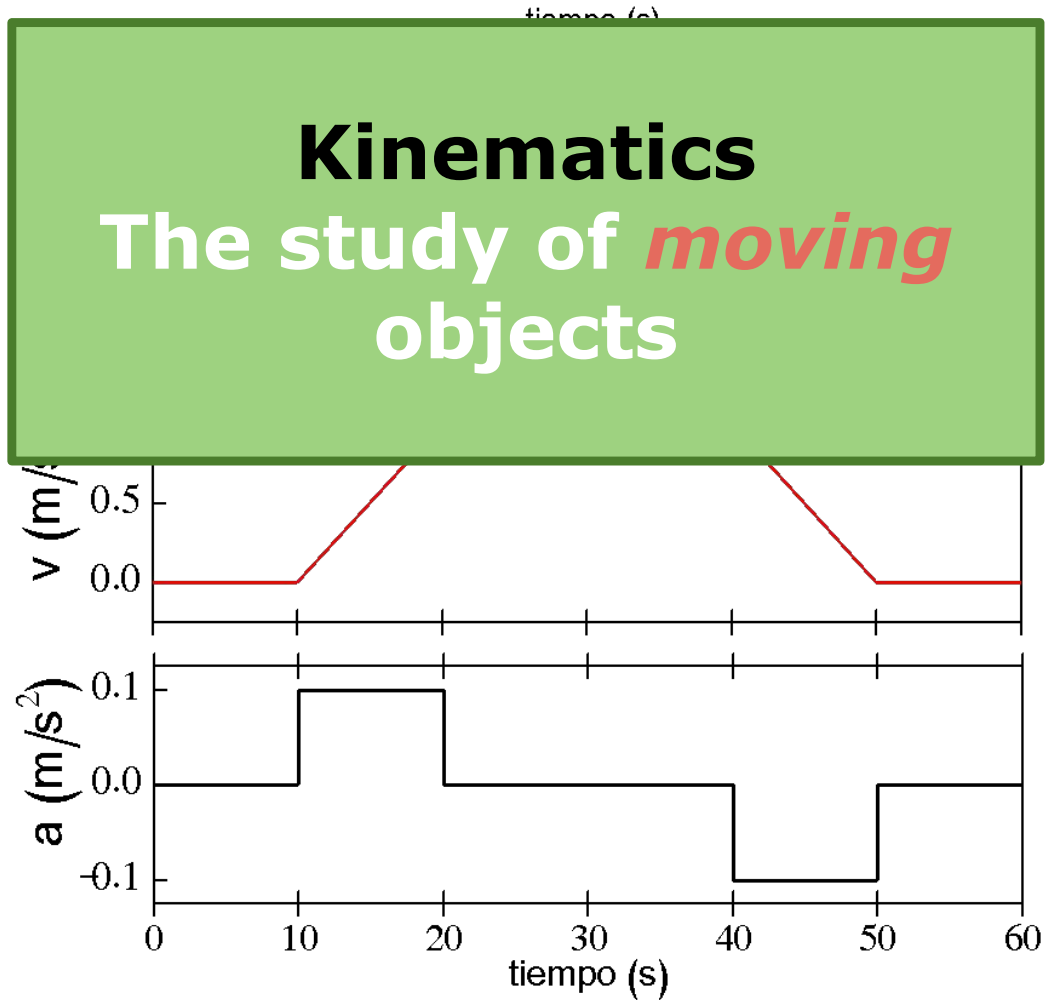
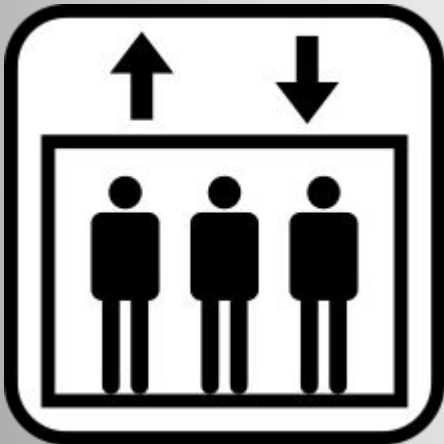
$$x = x_0 + v_0 * t + \frac{1}{2} a_0 t^2$$



Rectilinear motion in an elevator

Kinematics

The study of *moving* objects

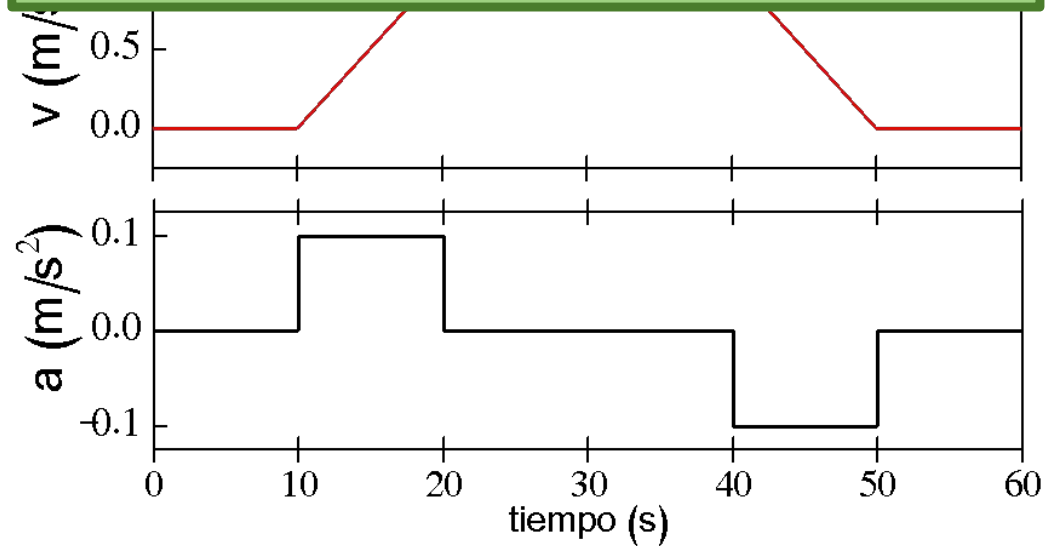


Rectilinear motion in an elevator



Kinematics

The study of *moving* objects



Rectilinear motion of a balloon

Basic Mechanics Theory Course

Starting from Trajectory data

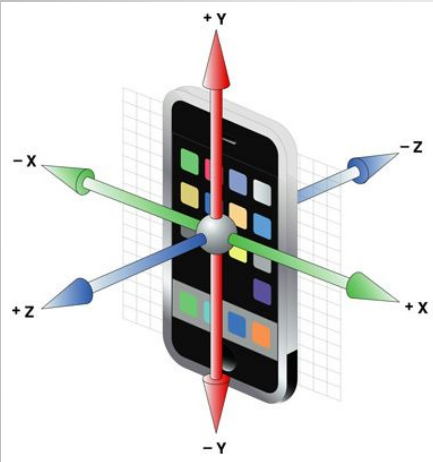
$$\begin{aligned}x(t) \\ v(t) &= dx/dt \\ a(t) &= dv/dt\end{aligned}$$

Starting from Newton second law

$$\begin{aligned}a(t) &= F/m \\ v(t) &= v_0 + \int a(t) \\ dt\end{aligned}$$

$$x(t) = x_0 + \int v(t) \\ dt$$

Videos



Accelerometer

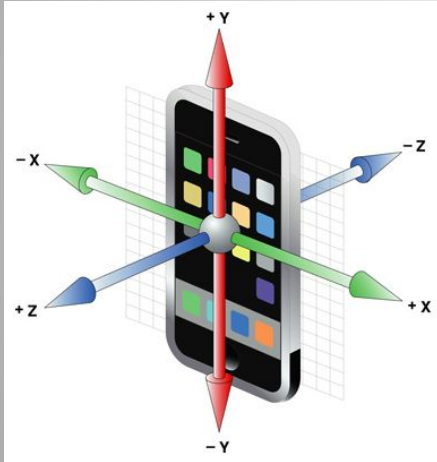
Differentiation vs. Integration

- **Didactic goals**
- **Accelerometer data**
 - Data acquisition
 - Analysis of data files
 - Numerical integration
- **Trajectory data**
 - Tracker software from OSP
 - Motion videos
 - Kinematic and Dynamic models

Outline

- **Use of Smartphone technology for experiments beyond traditional classroom or lab settings**
 - Smartphone sensors (accelerometer and video)
 - Autonomous learning (planning, creativity)
 - Team work (scientific discussion, social abilities)
- **Coordinated learning across different subjects**
 - Basic Mechanics (Physics/Math)
 - Introduction to Computational Physics (Physics)
 - Informatic Tools (Math)
- **Development of transverse competencies**
 - Theory+Experiment+Computation

Didactic goals



Starting from Newton second law

$$a(t) = F/m$$

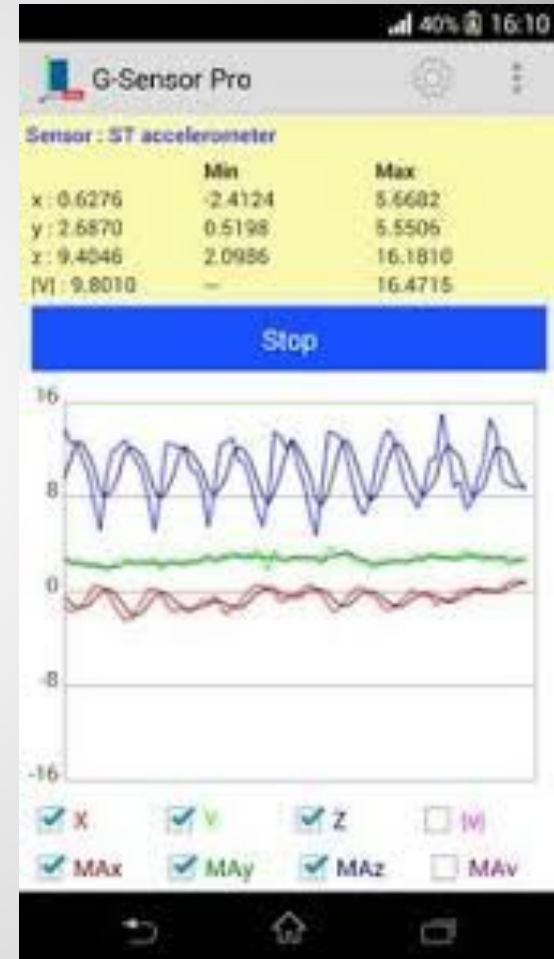
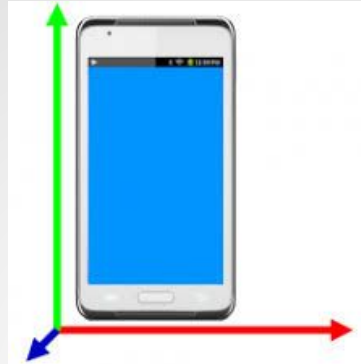
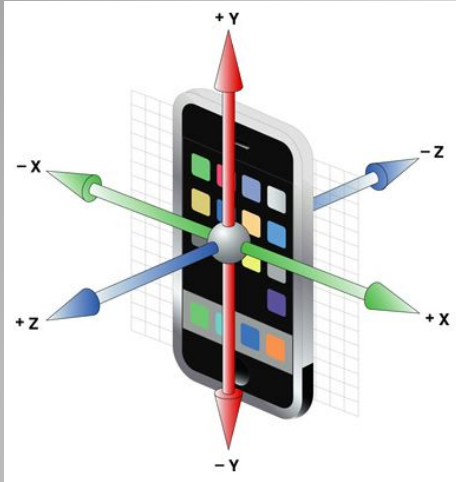
$$v(t) = v_0 + \int a(t) dt$$

$$x(t) = x_0 + \int v(t) dt$$

Smartphone accelerometer

Data Acquisition, Data Analysis, Numerical Integration

Android Free App: G Sensor logger

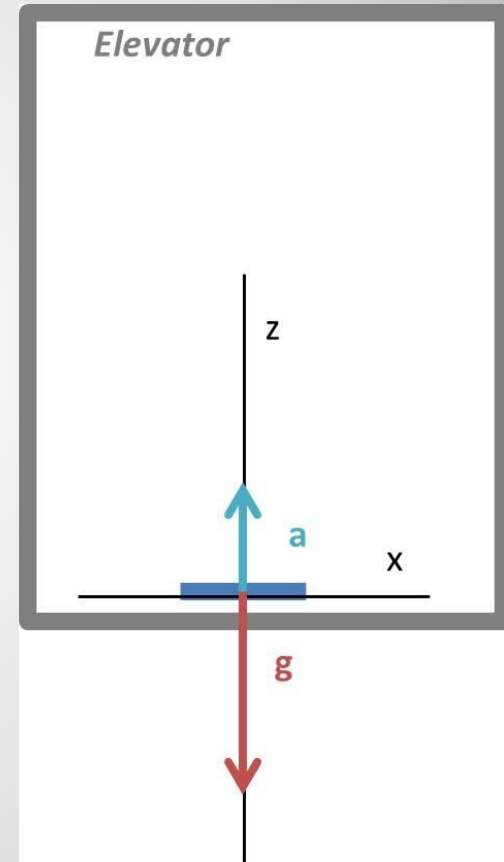
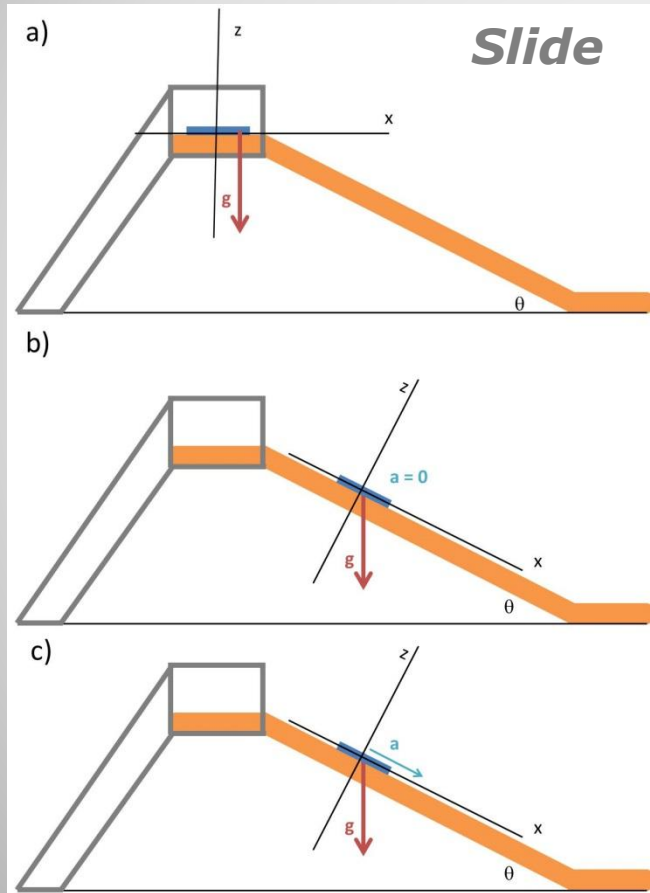


```
# Accelerometer Data File
# Started @Mon Sep 19 20:07:25 GMT+02:00 2016
#
# data format:
# so we have 4 columns with values separated by the " "
# X Y Z time_from_previous_sample(ms)

# sensor speed set to:FASTEST
# units set to: m/sec^2
# gravity NOT filtered out
# Accuracy: HIGH
-0.001      0.008  9.84   0
0.01      0.012  9.823  10
-0.019     0.01   9.837   9
0.0        -0.002  9.844  12
-0.026     0.006  9.835  11
```

Smartphone accelerometer: Data acquisition

Basic Mechanics: autonomous data acquisition in simple problems of rectilinear motion.

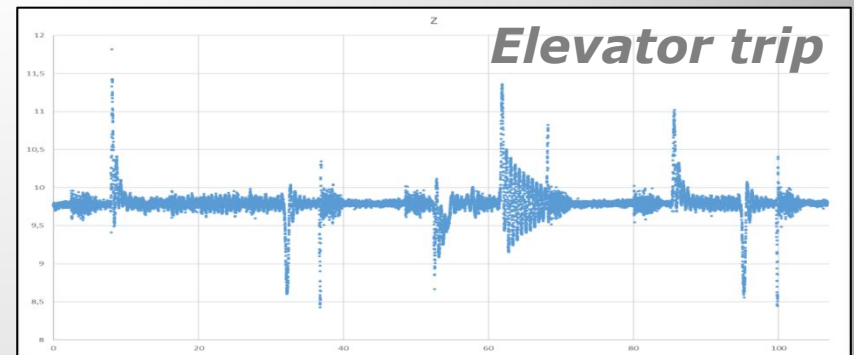


Smartphone accelerometer: Data acquisition

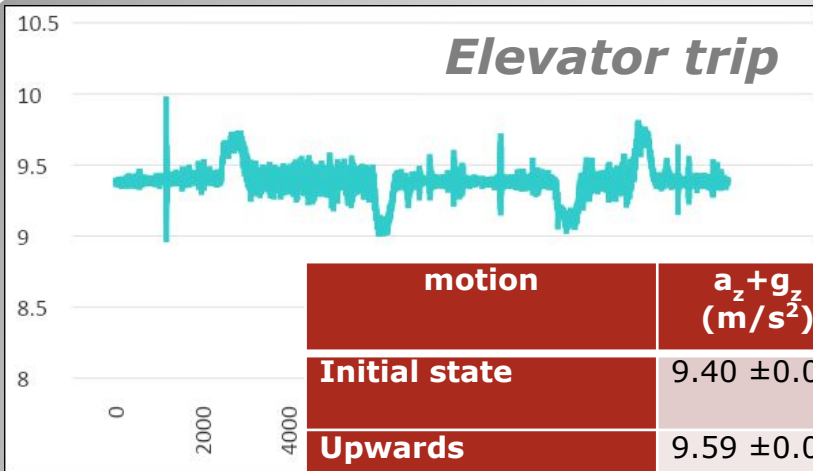
Introduction to Computational Physics Excel spreadsheet

Informatic Tools Plot Workshop

Import data, make graphs, calculate averages and statistical errors



Smartphone accelerometer: Data Analysis



$$a = 0$$

$$v = v_0 + a_0 t$$

$$z = z_0 + v_0 t$$

$$a = a_0$$

$$v = v_0 + a_0 t$$

$$z = z_0 + v_0 t + \frac{1}{2} a_0 t^2$$

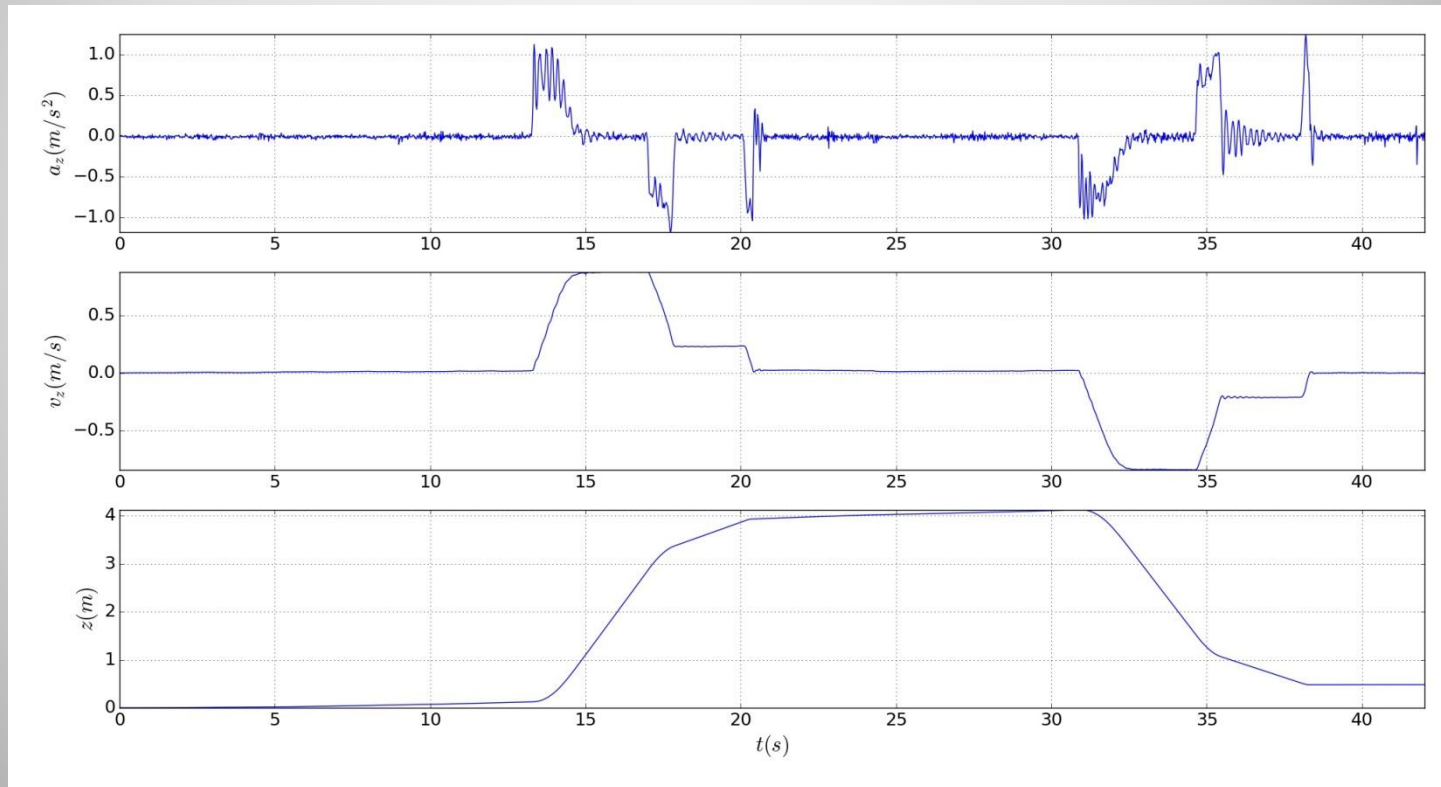
motion	$a_z + g_z$ (m/s^2)	$(a_z + g_z) - g_z$ (m/s^2)	Dt (s)	v_i (m/s)	v_f (m/s)	z_i (m)	z_f (m)
Initial state	9.40 ±0.03	0	12.12	0	0	0	0
Upwards acceleration	9.59 ±0.09	+0.19	3.38	0	0.65	0	1.10
Upwards uniform motion	9.39 ±0.06	0	14.5	0.65	0.65	1.102	10.55
Upwards deceleration	9.17 ±0.12	-0.22	2.7	0.65	0.05	10.55	11.52
Intermediate Stop	9.38 ±0.03	0	18.5	0	0	11.52	11.52
Downwards acceleration	9.16 ±0.07	-0.22	2.89	0	-0.63	11.52	10.61
Downwards uniform motion	9.39 ±0.06	0	6.17	-0.63	-0.63	10.61	6.74
Downwards deceleration	9.60 ±0.12	+0.22	2.64	-0.63	-0.05	6.74	5.83
Final Stop	9.39 ±0.03	0	8.3	0	0	5.83	5.83

Smartphone accelerometer: Data Analysis

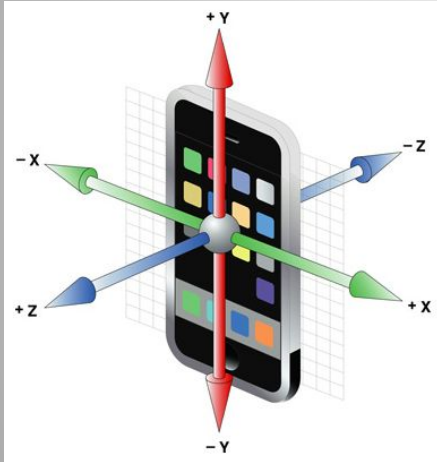
Euler integration of acceleration, velocity data

$$\begin{aligned}v(0) &= 0 \\v(t_{i+1}) &= v(t_i) + a_z(t_i) \times (t_{i+1} - t_i)\end{aligned}$$

$$\begin{aligned}z(0) &= z_0 \\z(t_{i+1}) &= z(t_i) + v(t_i) \times (t_{i+1} - t_i)\end{aligned}$$



Smartphone accelerometer: Numerical integration

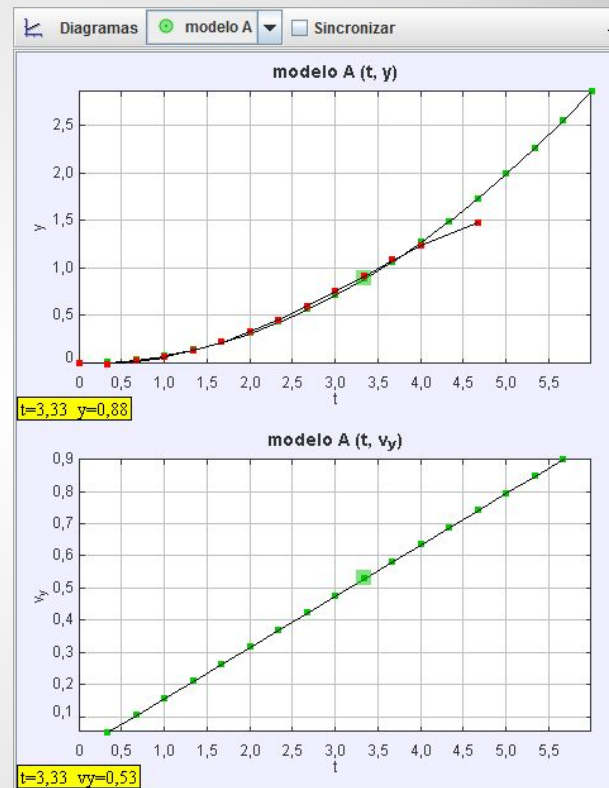
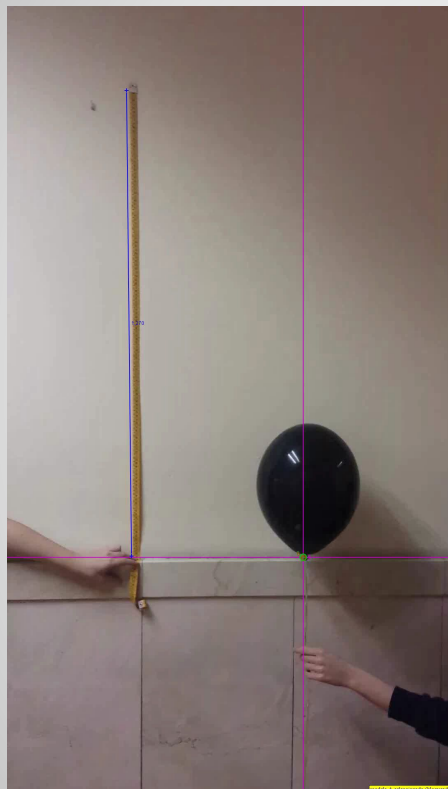


Starting from Trajectory data

$$x(t)$$
$$v(t) = dx/dt$$
$$a(t) = dv/dt$$

Trajectory data from Smartphone videos

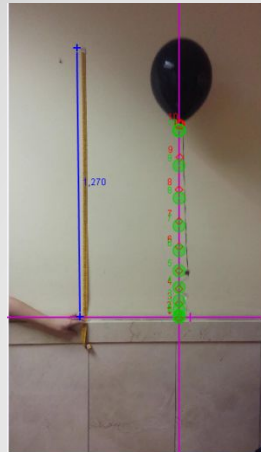
Tracker software from OSP, Motion videos, Kinematic and Dynamic models



<https://physlets.org/tracker/>

Trajectory data: Tracker Software from OSP

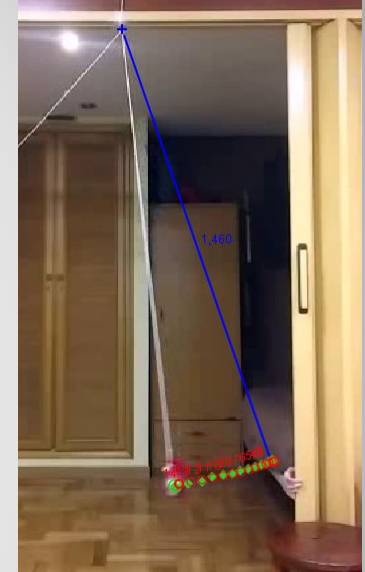
Arquimedes



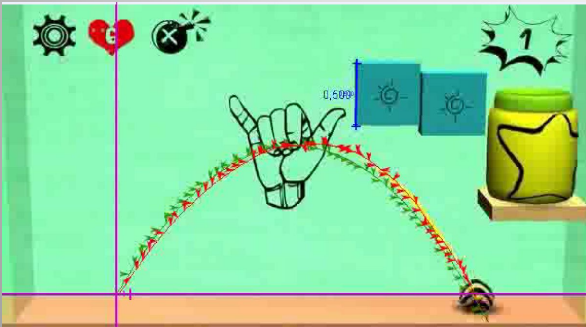
Ball rolling down a plane



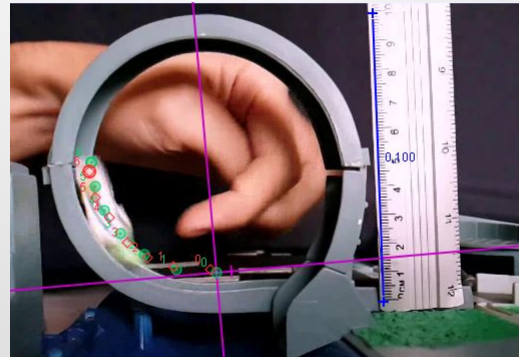
Pendulum



Gravity in videogames



Car in a loop



Student videos

- Team work
- Creativity

Trajectory data: Motion Videos

1. Record video of simple, planar motion

2. Import into Tracker software



3. Select time scale, initial and final time (fps)



4. Pixel/meter calibration using size of known object in video



5. Define coordinate axes

6. Define moving object position in each image frame to obtain experimental trajectory data

 Create

7. Visualize velocity and acceleration vectors



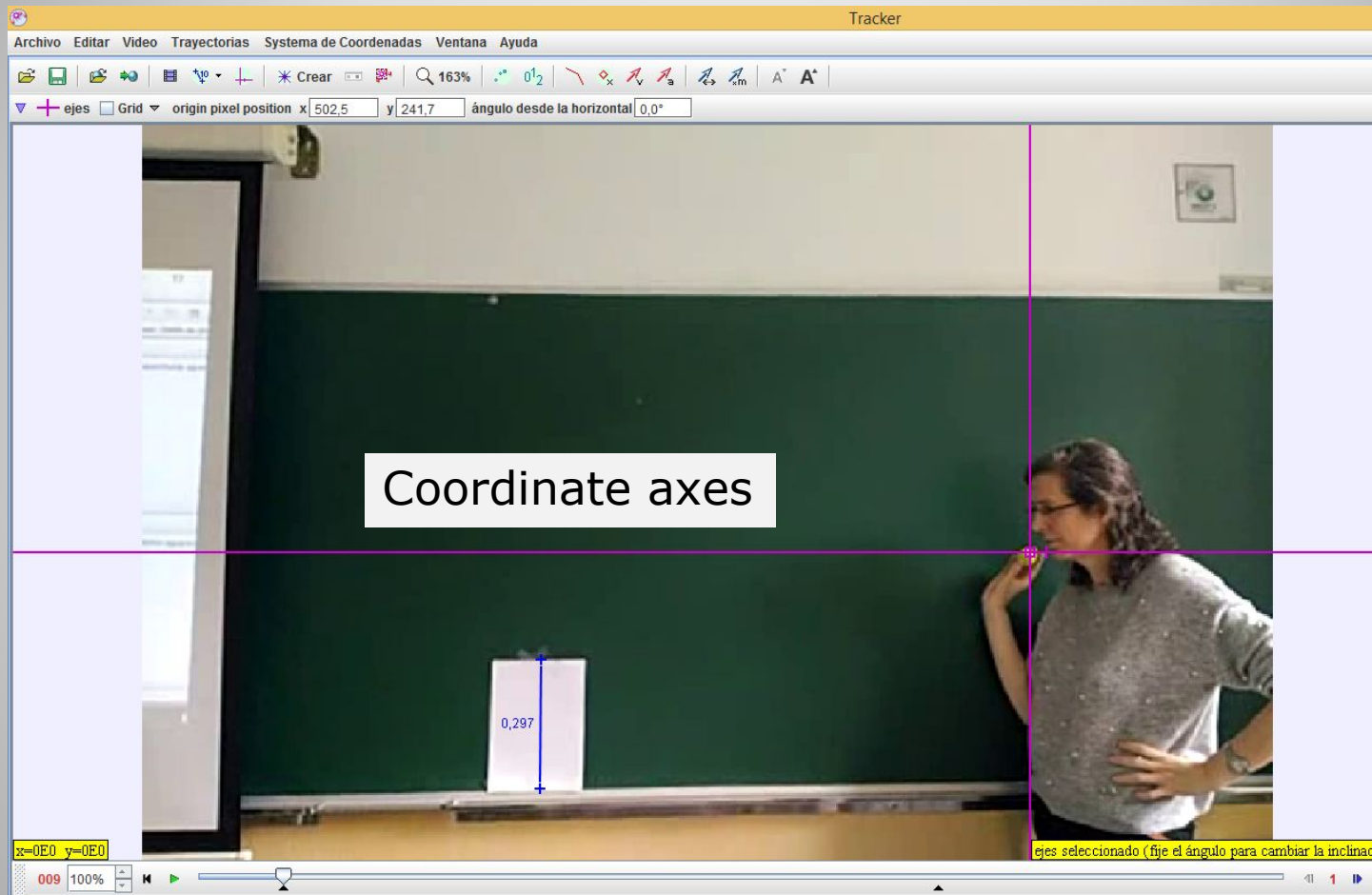
8. Analyze trajectory with kinematic or dynamic models

Trajectory data: Motion Videos

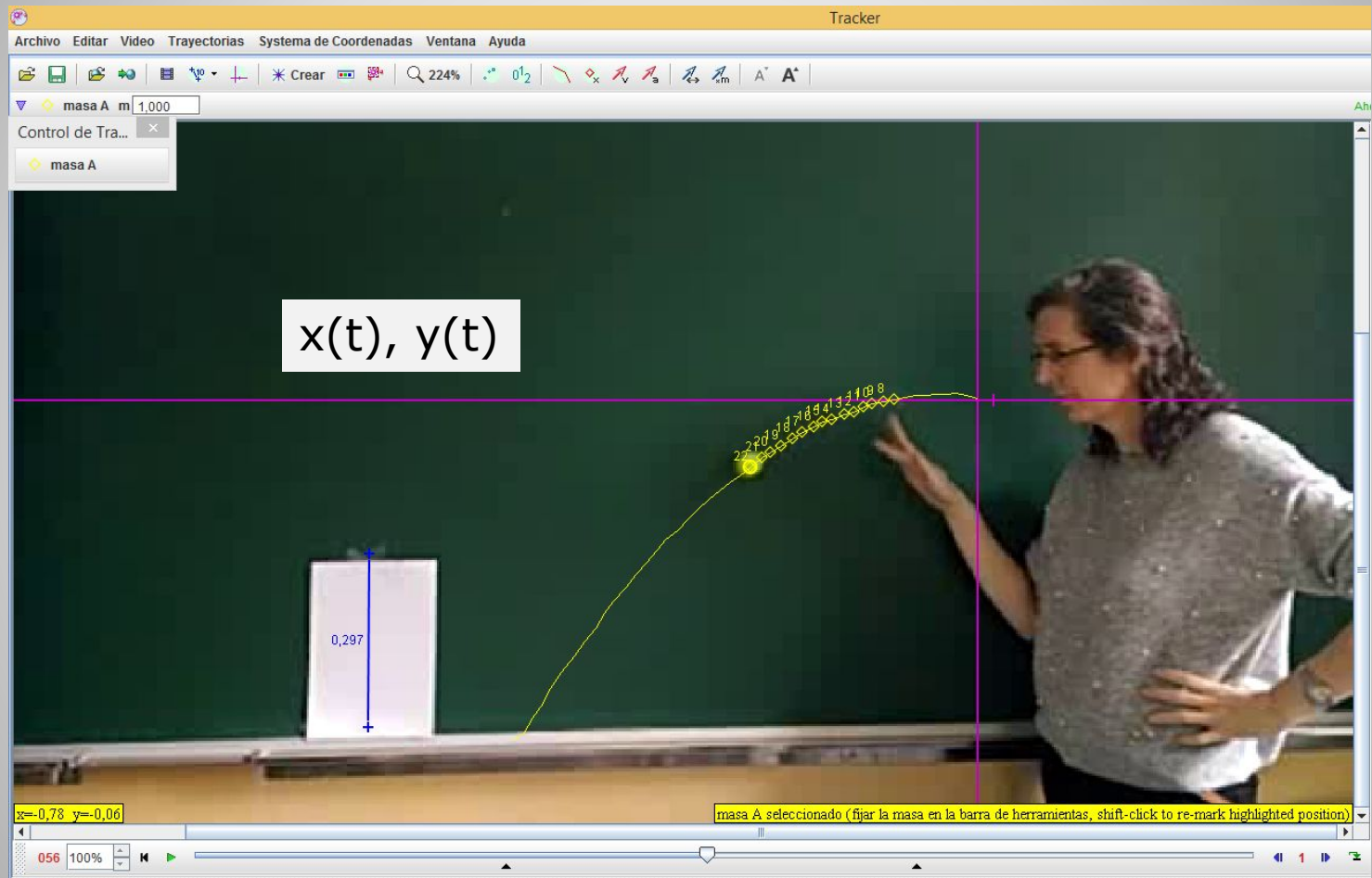
Time scale: 120 fps

297 mm

Trajectory data: Motion Videos

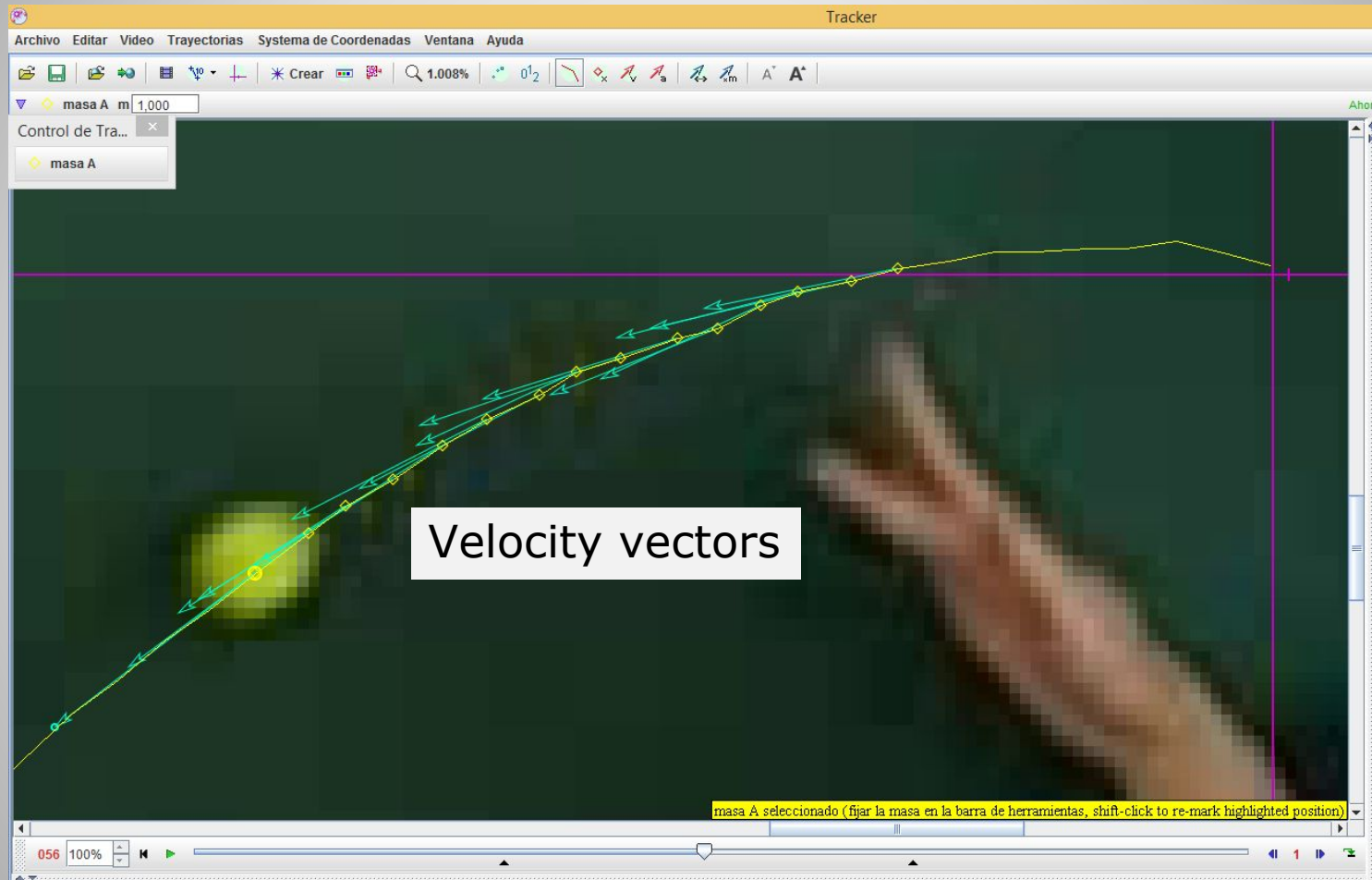


Trajectory data: Motion Videos



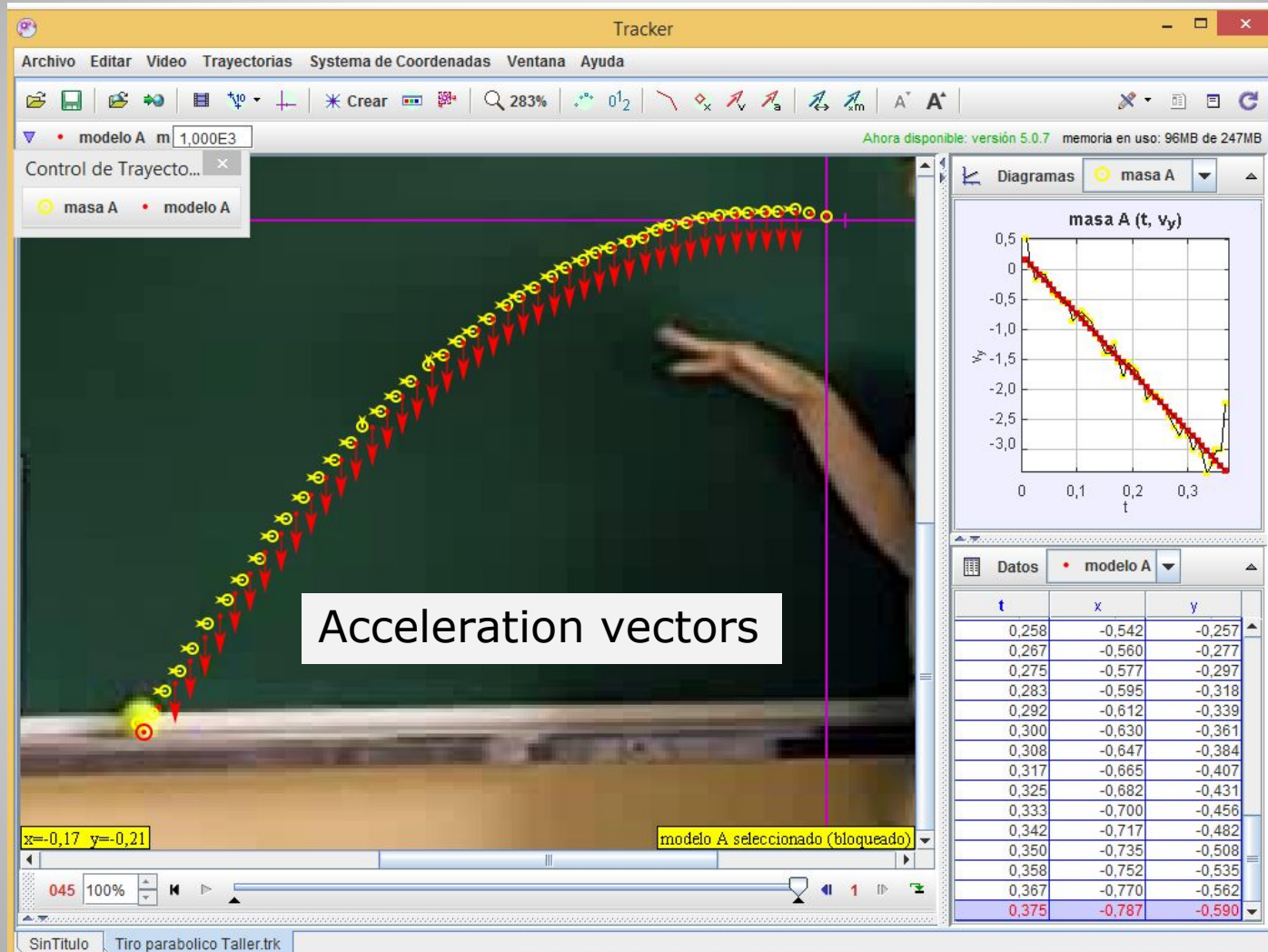
Trajectory data: Motion Videos

Numerical differentiation



Trajectory data: Motion Videos

Numerical differentiation



Trajectory data: Motion Videos

$$x = x_0 + v_0 t$$

$$y = y_0 + v_0 t - \frac{1}{2} g t^2$$

$$a(t) = F/m$$

$$v(t) = v_0 + \int a(t) dt$$

Constructor de modelos: Kinematic Particle

Inicio: 0 Fin: 45 Launcher: (none)

Modelo: modelo B

Parámetros

Nombre	Expresión
m	1
v0x	-2,1
v0y	0,25
g	9,8

Valores Iniciales

Nombre	Expresión
t	0

Funciones de Posición

Nombre	Expresión
x	v0x*t
y	v0y*t-g*t*t/2

Haga doble-clic en la celda para editarla. Consulte la Ayuda para ver las expresiones válidas.

Ayuda Deshacer Rehacer Tamaño de la Fuente Cerrar

Constructor de modelos: Dynamic Particle (Cartesian)

Inicio: Fin: 45 Launcher: (none)

Modelo: modelo A

Parámetros

Nombre	Expresión
m	1.0E3
g	9,8

Valores Iniciales

Nombre	Expresión
t	0
x	0
y	0,005
vx	-2,1
vy	0,25

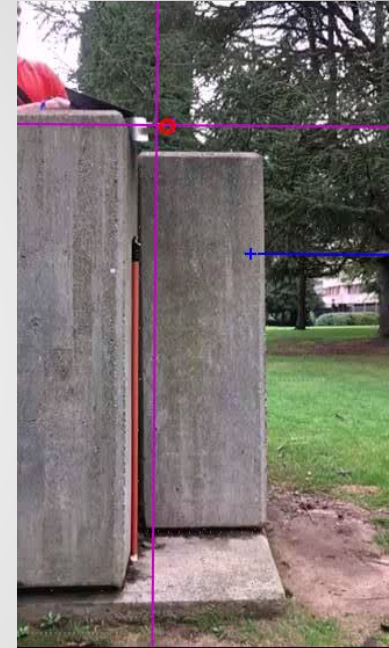
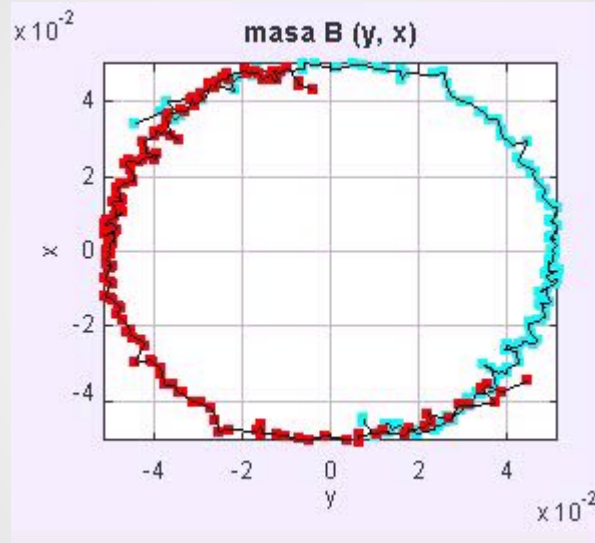
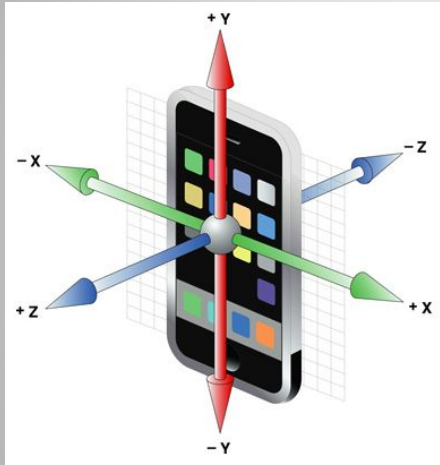
Funciones de Fuerza

Nombre	Expresión
fx	0
fy	-m*g

Haga doble-clic en la celda para editarla. Consulte la Ayuda para ver las expresiones válidas.

Ayuda Deshacer Rehacer Tamaño de la Fuente Cerrar

Trajectory data: Kinematic and Dynamic models



ado (fijar la masa en la barra de herramientas, mayúscula

Experimental proof of Murphy's law

Results of innovation project

Academic indicators, shared innovation resources

Subject	Participation	Satisfaction (max. 5)	Academic results (improvement over average)
Basic Mechanics	70-90 %	3.1	60%
Informatic Tools	100%	3.5	53%
Introduction to Computational Physics	50%	3.9	73%

150 students/year

Academic Indicators



Real
Sociedad
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Física

R.S.E.F.

Móviles en clase de Mecánica: estudio del movimiento de un ascensor



R. D. Crespo
Dpto. Física, Universidad de Oviedo, Oviedo

36 RdF • 31-4 • Octubre-diciembre 2017

S. I. Díaz
Dpto. Informática, Universidad de Oviedo, Oviedo



J. Fernández Menéndez
Dpto. Física, Universidad de Oviedo, Oviedo



M. R. Sierra
Dpto. Informática, Universidad de Oviedo, Oviedo



M. Vélez
Dpto. Física, Universidad de Oviedo, Oviedo, CINN
(CSIC-Universidad de Oviedo), El Entrego, España



Notas de clase

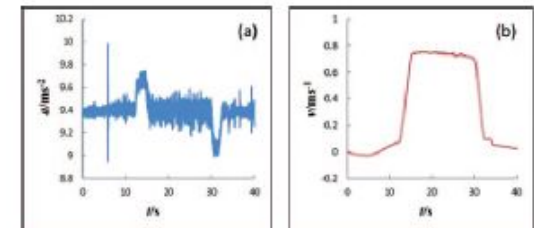
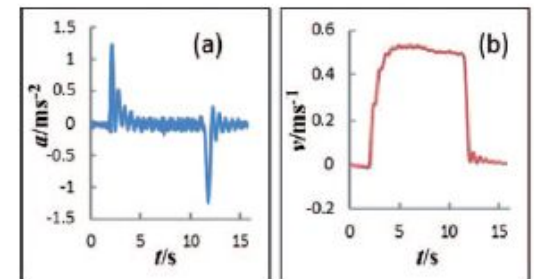



Figura 2. (a) Aceleración, a , en función del tiempo, t , durante el trayecto de subida del ascensor entre dos plantas de un edificio; (b) Velocidad, v , en función del tiempo, t , obtenida mediante una integral numérica de los datos del panel (a). Nótese la variación aparente de la velocidad en periodos que deberían ser de reposo (0-10 s y 32-40 s) a causa de variaciones suaves en g .



**Shared innovation resources beyond Physics and Math
degrees at Science Faculty of University of Oviedo**

Shared Accelerometer computational exercises



Home Exercise Sets Faculty Commons Resources Community


Exercise Sets » Study of rectilinear motion with a smartphone: Elevators and Slides

This Exercise Set has been submitted for peer review, but it has not yet been accepted for publication in the PICUP collection.

Study of rectilinear motion with a smartphone: Elevators and Slides

Developed by [R.D. Crespo](#), [A. García-Fuente](#), [M. R. Sierra](#) and [M. Vélez](#)

In this set of exercises students will measure the time dependence of the acceleration in different situations using the internal accelerometer of their Smartphones. Two experiments are proposed: the uniform acceleration motion of the Smartphone going down a slide and the rectilinear motion of an elevator going from one floor to the other. The students will import the acceleration vs. time data, plot them and obtain averages on the chosen time intervals in order to analyze them with simple mechanics models. They will also perform a numerical integration of the elevator acceleration in order to obtain the time dependent velocity and position and compare it with the actual experimental trajectory.



Subject Areas Mechanics and Experimental Labs
Level First Year

<https://www.compadre.org/PICUP/exercises/exercise.cfm?I=314&A=Smartphone>

Shared innovation resources beyond Physics and Math degrees at Science Faculty of University of Oviedo

Physics Olympiads at Asturias



9th March 2019

- **60 students (2 BAC)**
- **20 High school centers**
- **3 students selected for National Olympic contest**



- **Tracker workshop for 12 High School Teachers**
- **Tracker laboratory for selected students**

Shared innovation resources beyond Physics and Math degrees at Science Faculty of University of Oviedo

Shared Tracker Digital libraries

Physics Department
at Univ. Oviedo



Open Source Physics
Web page

p/fisica/biblioteca

Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo

Bienvenido MARIA VELEZ FRAGA

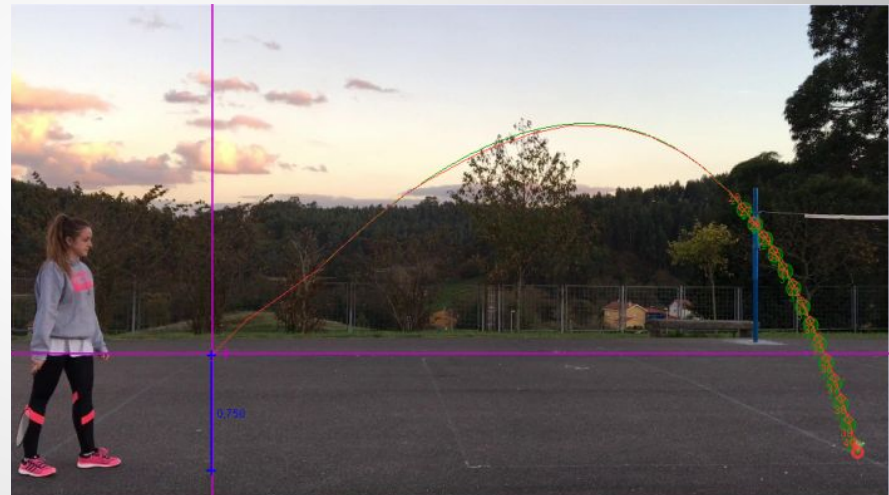
Departamento de Física

Zona Privada » Biblioteca Digital TRACKER

Biblioteca Digital TRACKER

Biblioteca Digital TRACKER

- [Badminton shuttlecock with air resistance](#)
- [Falling ball with uniform acceleration](#)
- [List of contents](#)
- [Looping with friction](#)
- [Murphy Law Univov1](#)
- [Murphy Law Univov2](#)
- [Pendulum with polar coordinates](#)
- [Physics_uniovi](#)
- [Physics_uniovi_local](#)



<http://www.per-central.org/items/detail.cfm?ID=14553>

Open digital library... coming soon

**Sharing innovation resources beyond Physics and Math
degrees at Science Faculty of University of Oviedo**

- **Smartphone** as a *lab in your pocket* technology: **accelerometer and video**
- **Coordination** between different subjects
- **Autonomous learning**, team work, creativity
- **Networking** at different teaching levels

Conclussions