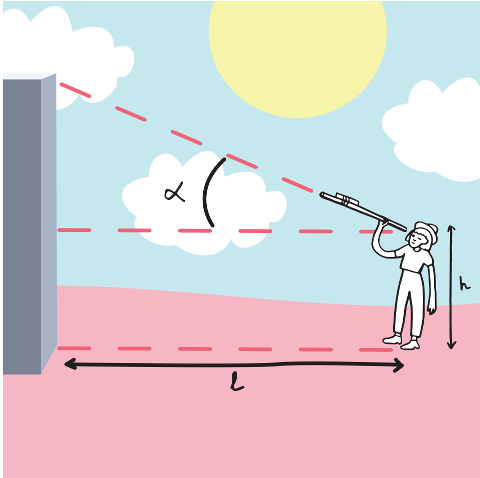
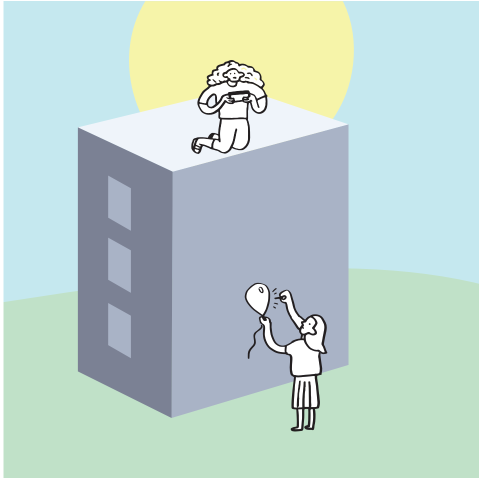
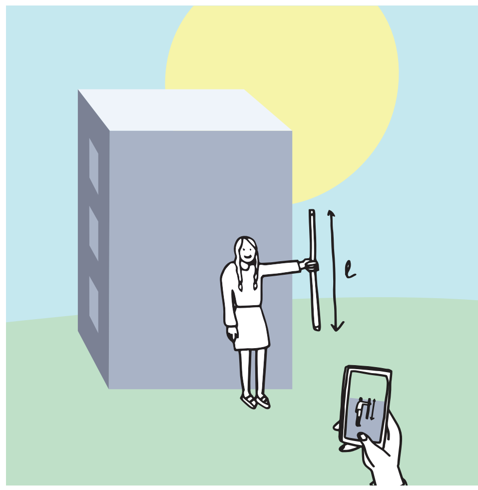


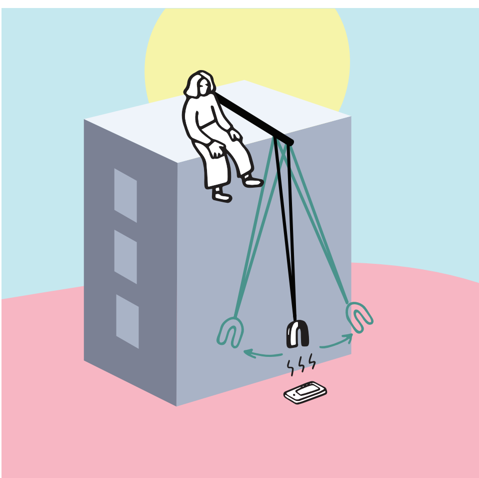


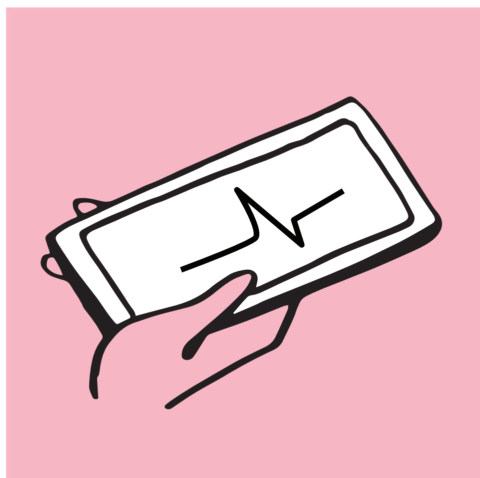
Theme:

MECHANICS

All the methods using mechanics principles and smartphones to determine the height of a building.







Discover The Smartphone Physics Challenge at VULGARISATION.FR

«Physics Reimagined» team (Paris-Saclay University)

Precision: high

Difficulty: low

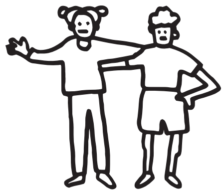
№1. Free Fall of the Smartpone

Formula

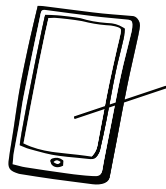
$$\begin{cases} H = \frac{1}{2} g t^2 \\ \text{or} \\ H = \iint \ddot{z} \, dt \end{cases}$$

Material

1 sheet

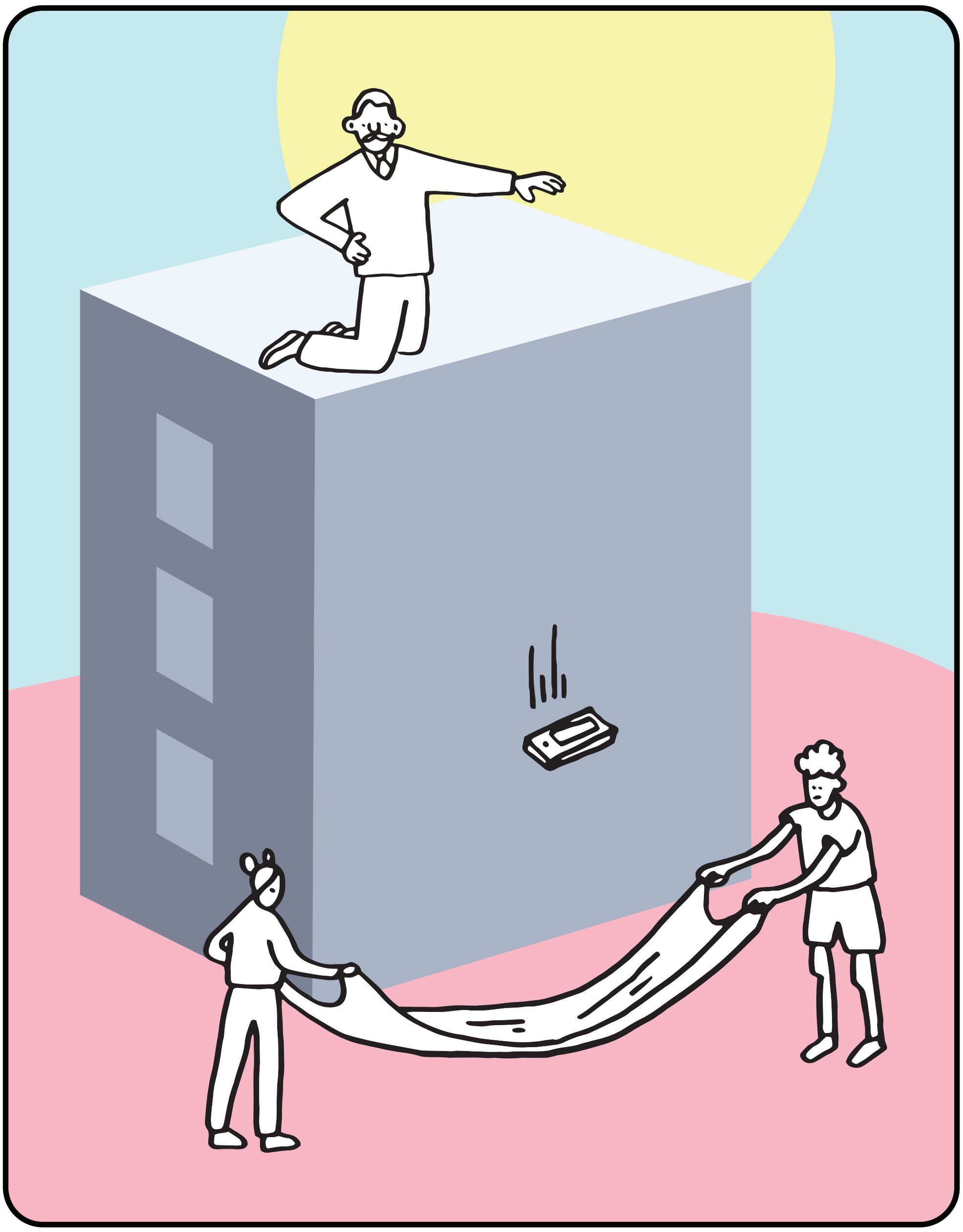


two friends

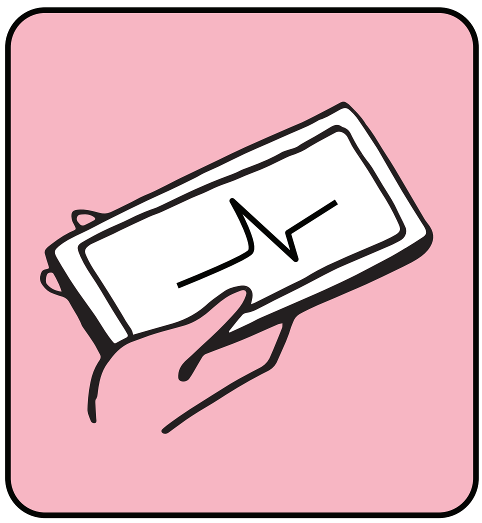


Sensor: **accelerometer**

1 smartphone



Drop your smartphone from the top of the building, your friends receiving it down in a sheet, like firefighters. The recording of the accelerometer data makes it possible to determine the time of fall, and if needed the value of the acceleration can be used to take air drag into account.



t = fall time of the smartphone,
$\ddot{z}$ = smartphone's acceleration,
$g = 9.8\ ms^{-2}$

Precision: intermediate

Difficulty: minimum

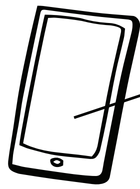
№2. Free Fall & Stopwatch

Formula

$$H = \frac{1}{2} g t^2$$

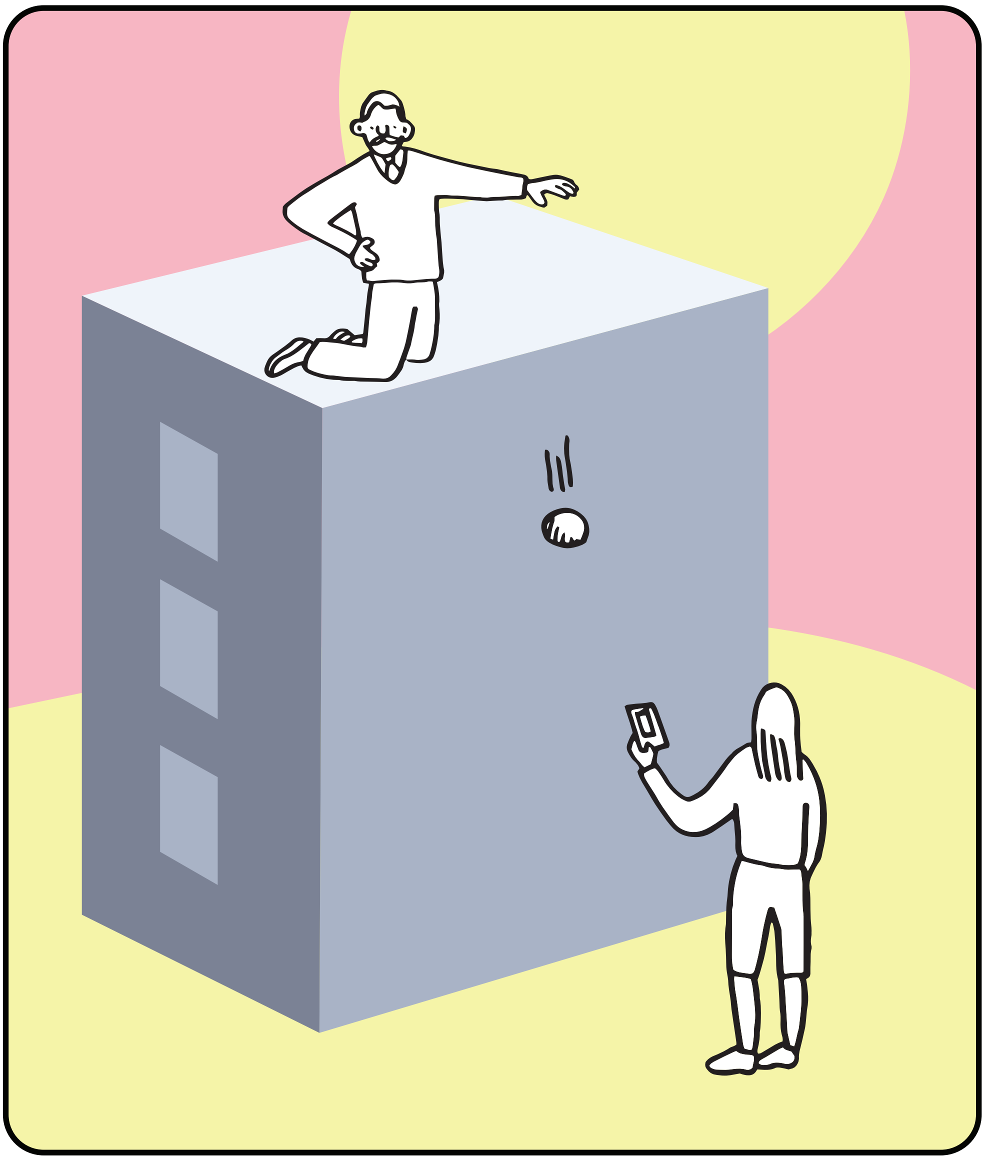
Material

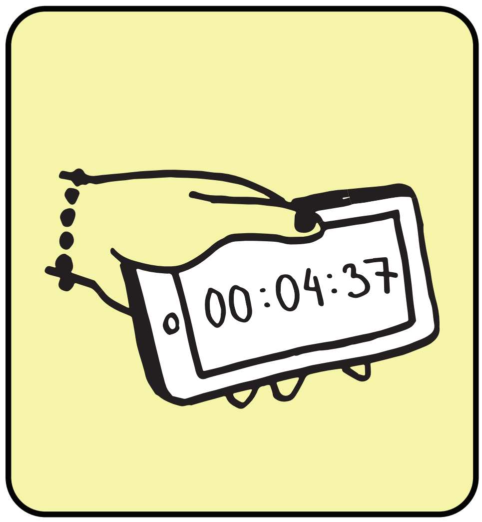
1 ball



Sensor: **stopwatch**

1 smartphone





Drop the ball from the top of the building. Time the fall.

t = fall time of the ball,
$g = 9.8\ ms^{-2}$

The formula does not consider air drag.

Precision: high

Difficulty: minimum

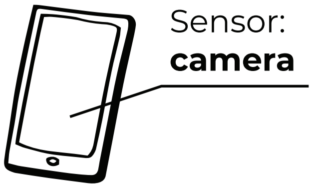
№3. Free Fall Filmed

Formula

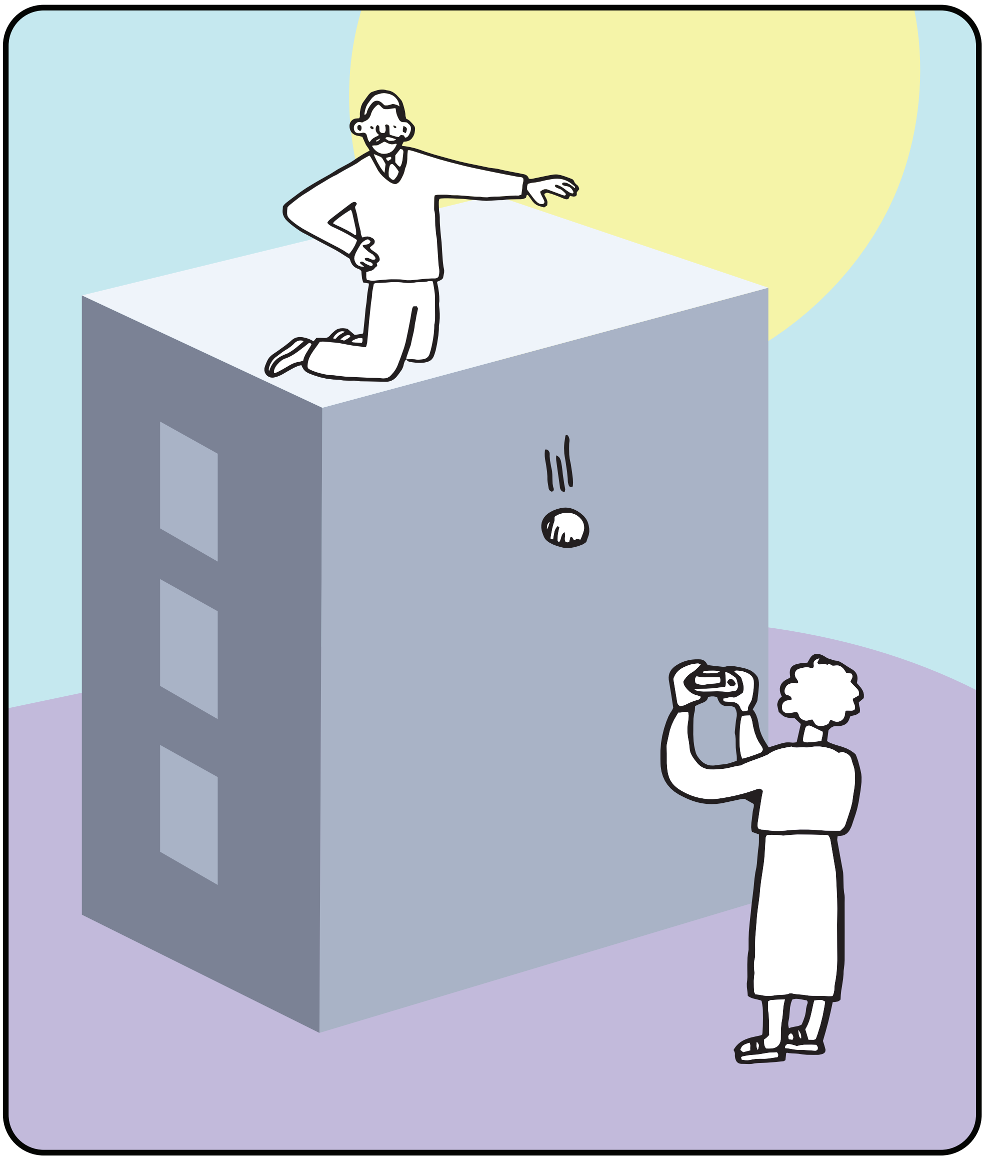
$$H = \frac{1}{2} g t^2$$

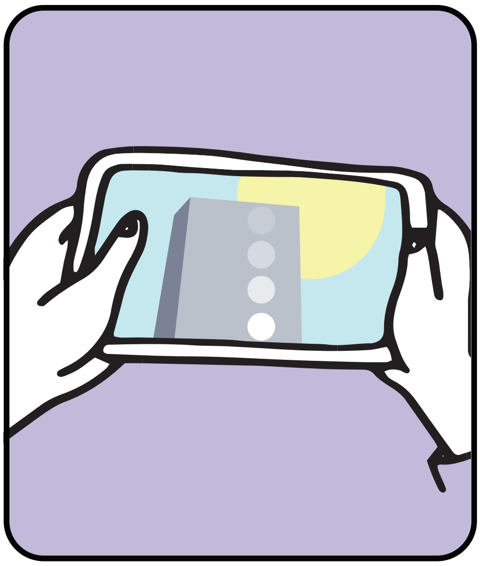
Material


1 ball



1 smartphone





Drop the ball from the top of the building. Film the fall and determine its duration.

t = fall time of the ball,
g = 9.8 ms^{-2}

The formula does not consider air drag.

Precision: high

Difficulty: low

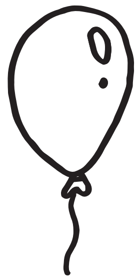
№4. Sound of a Free Fall

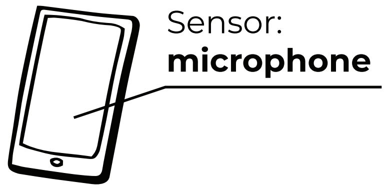
Formula

$$H = \frac{1}{2} g t^2$$

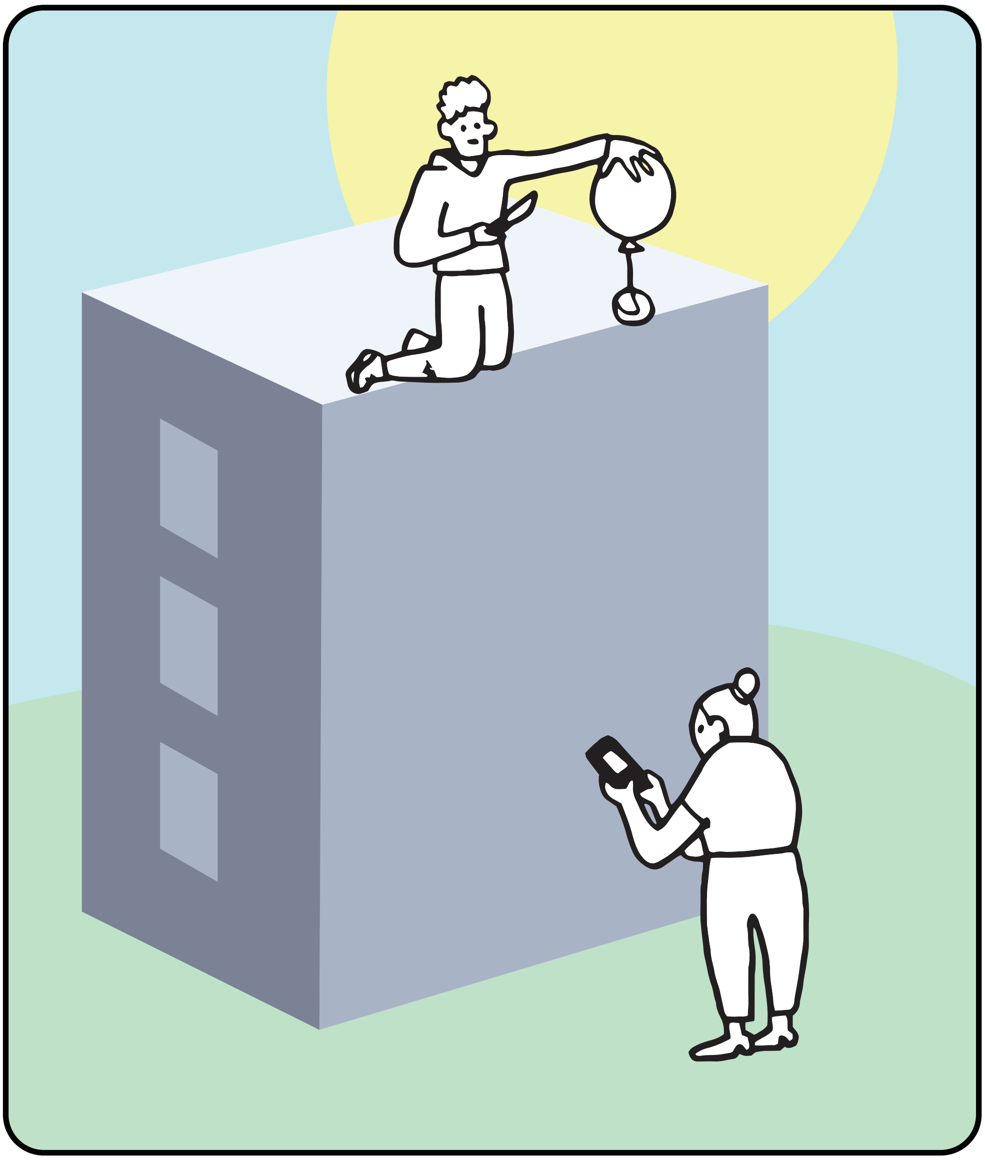
Material


1 ball


1 balloon

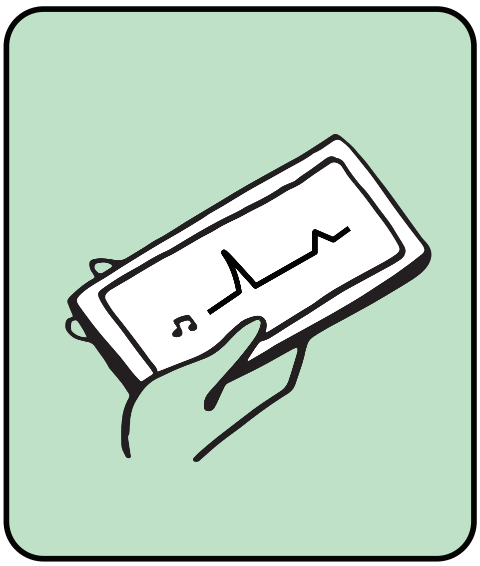

Sensor: **microphone**

1 smartphone



Attach the ball to the balloon. Go to the top of the building, and let the ball fall by popping the balloon. The smartphone is at the bottom of the building and records the sound to determine the time of fall.

t = fall time of the ball,
$g = 9.8\ ms^{-2}$



The formula does not consider air drag.

Precision: intermediate

Difficulty: low

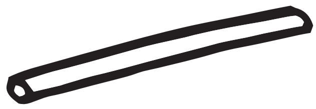
№5. End of the Fall Filmed

Formula

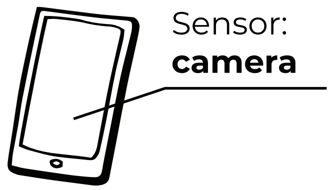
$$H = \frac{v^2}{2g}$$

Material

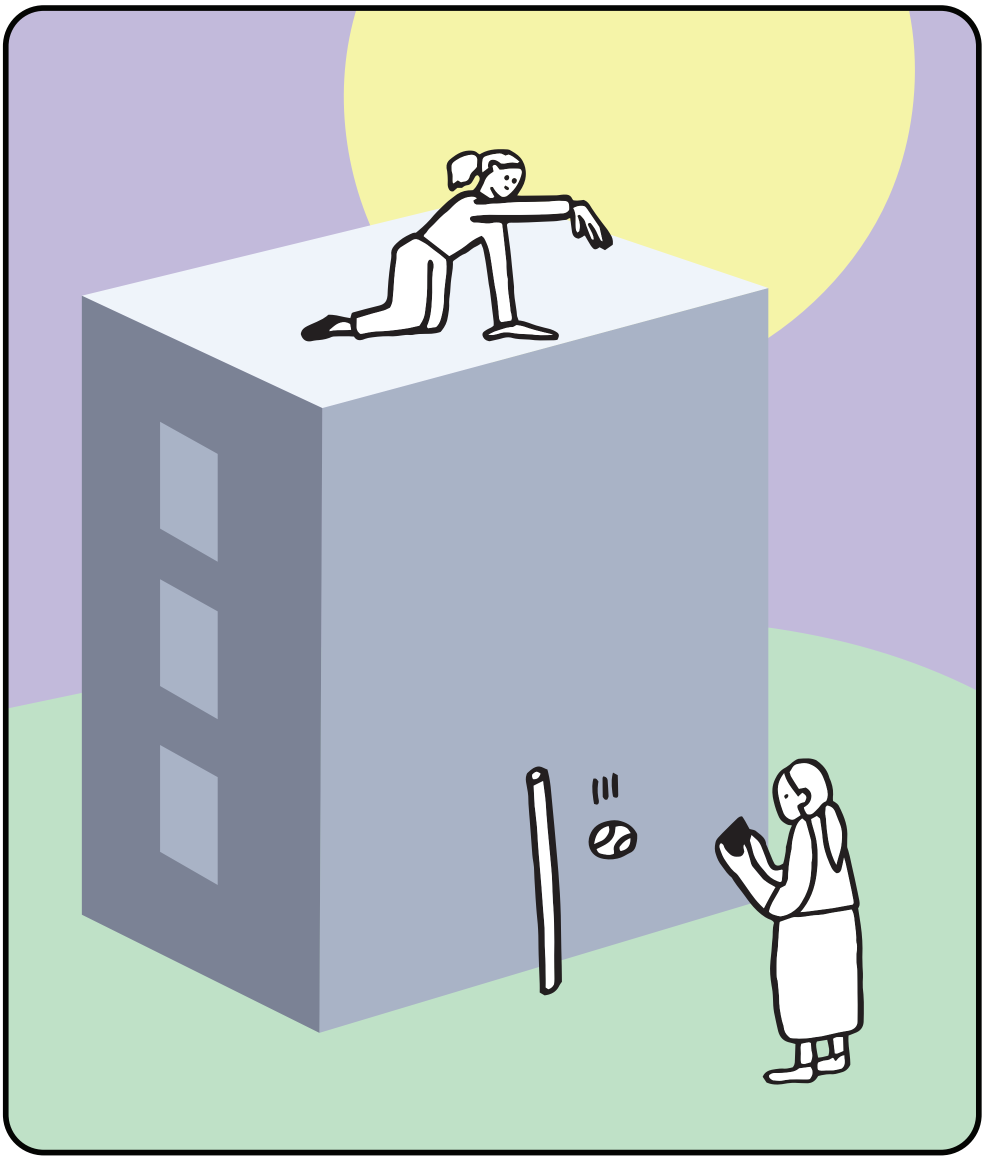
1 ball

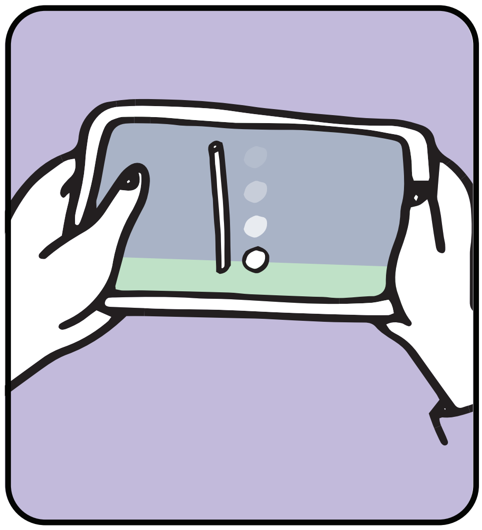


1 bar of known size



1 smartphone





Drop the ball from the top of the building. Film the last meters of the ball's fall, using the bar as a scale. Determine the final velocity of the ball.

v = ball's final velocity,
g = 9.8 ms^{-2}

The formula does not consider air drag.

Precision: intermediate

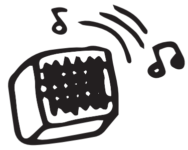
Difficulty: intermediate

№6. End of the Fall & Doppler

Formula

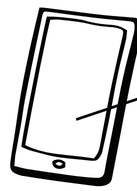
$$H = \frac{v^2}{2g}$$

Material



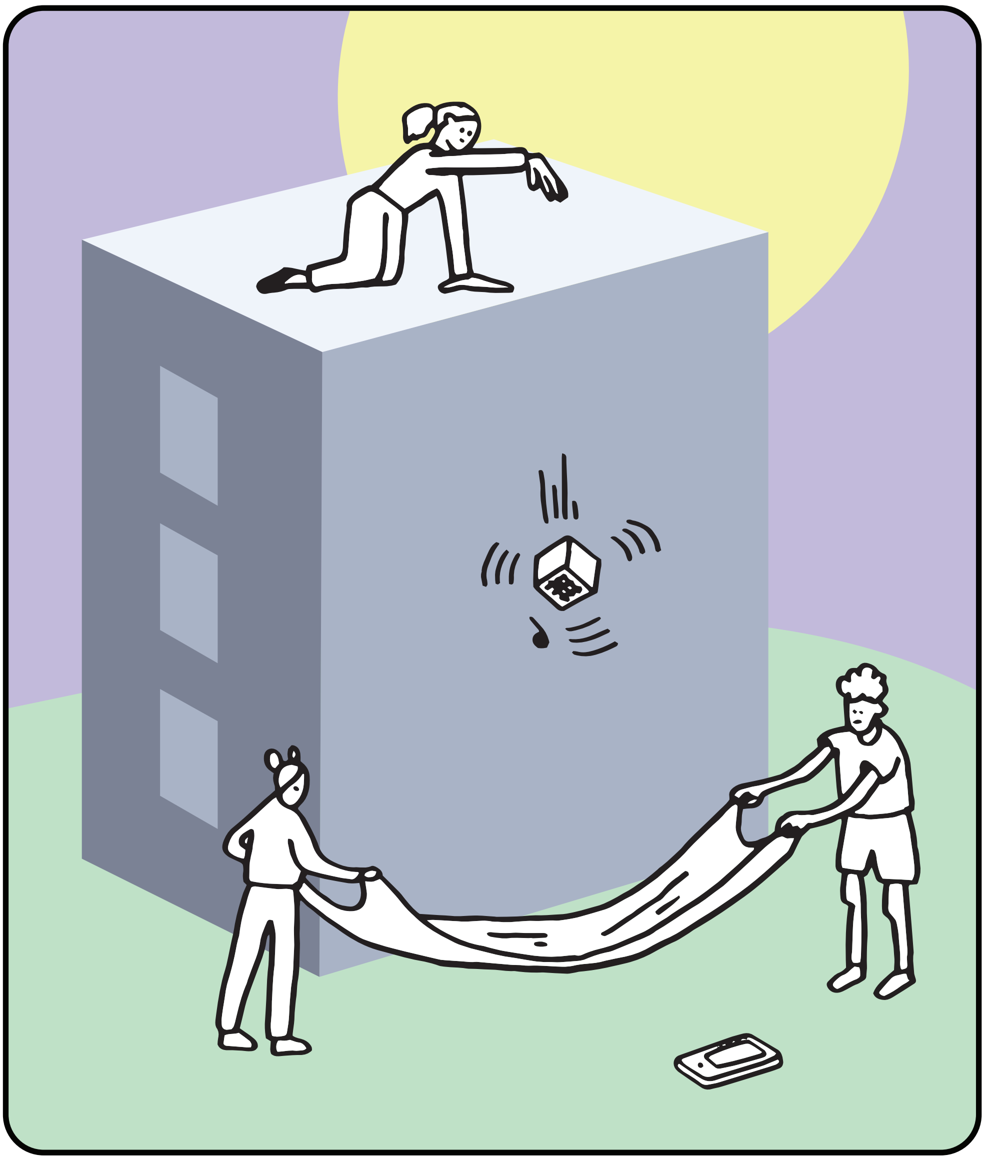
1 bluetooth speaker

1 sheet



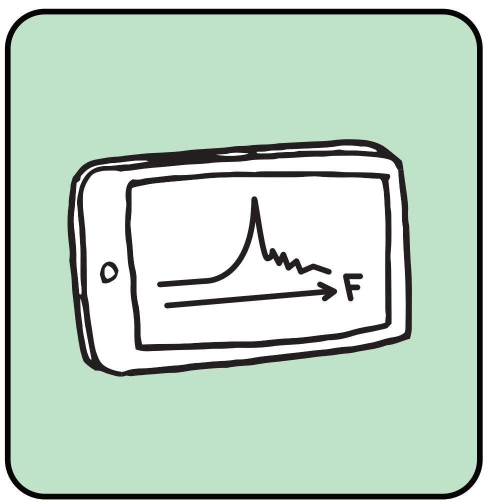
Sensor: **microphone**

1 smartphone



Let the loudspeaker fall from the top of the building, making it sound a continuous note. At the bottom, the smartphone records the sound to determine the speed of fall by Doppler effect. (Catch the speaker in a sheet stretched between two people.)

v = speaker's final velocity,
$g = 9.8\ ms^{-2}$



The formula does not consider air drag.

№7. Parabola

Precision: intermediate

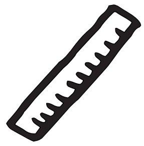
Difficulty: intermediate

Formula

$$H = \frac{1}{2} g \left(\frac{l}{v_0}\right)^2$$

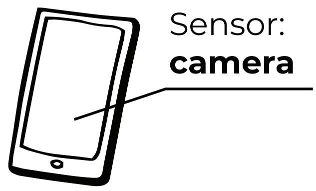
Material

1 tape measure

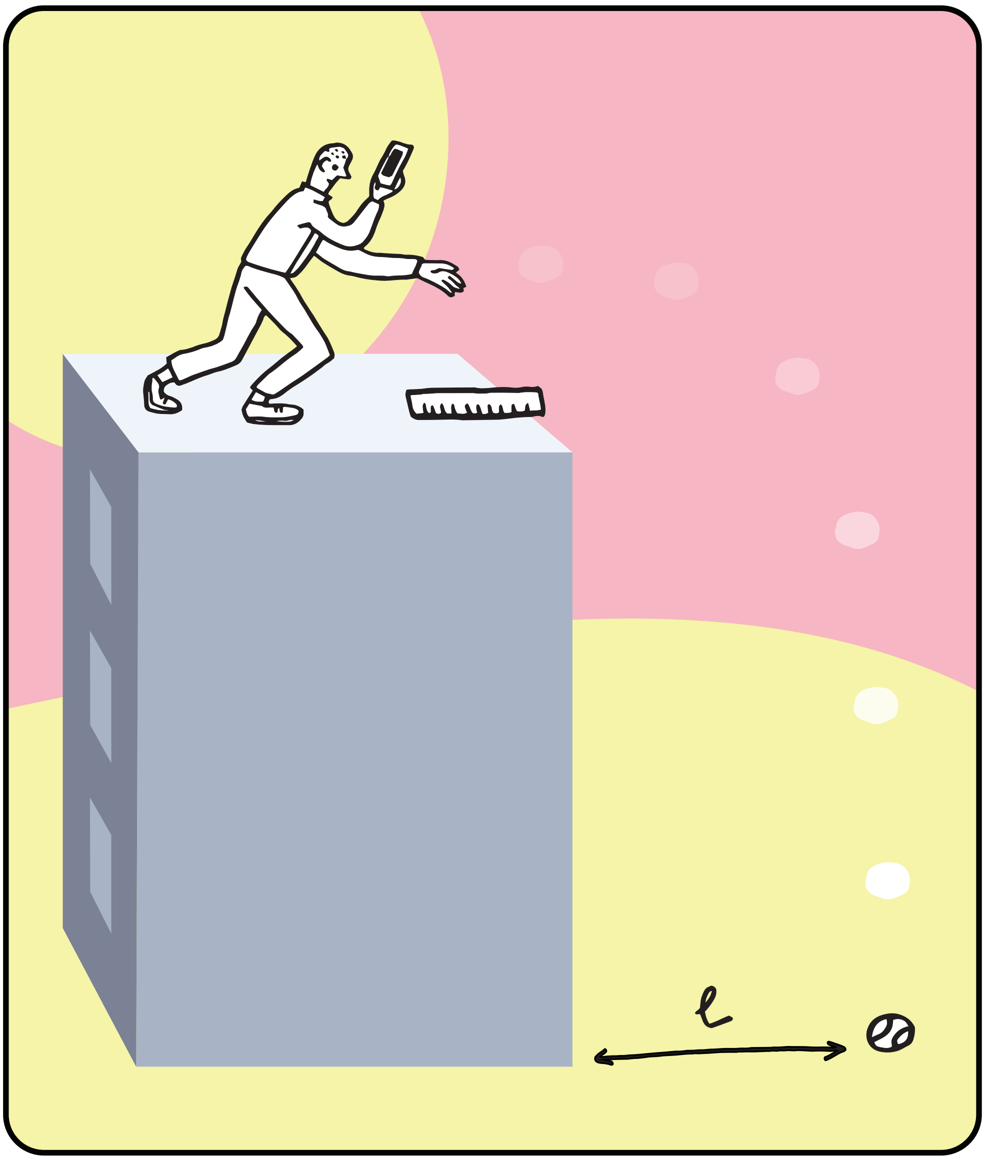


1 bar of known size

1 ball

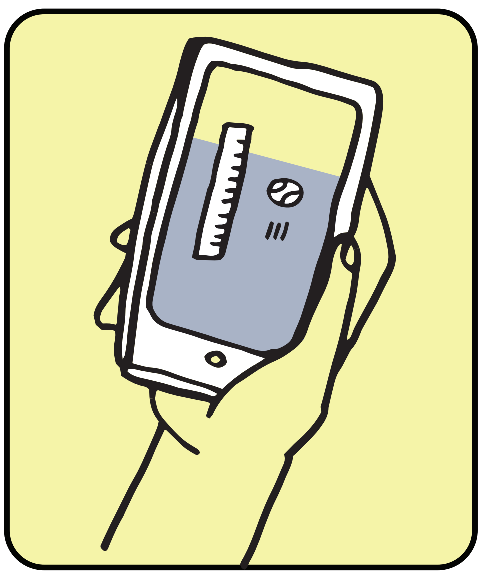


1 smartphone



From the top of the building, the ball is thrown horizontally. Film the throw to determine the initial velocity of the ball (the bar gives the scale). Measure the distance to the building where the ball is landing.

v_0 = horizontal velocity of the ball,
l = distance to the building where the ball touches the ground,
$g = 9.8\ ms^{-2}$



The formula does not consider air drag.

Precision: intermediate

Difficulty: low

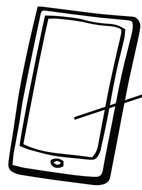
№8. Filmed Bounces

Formula

$$\begin{cases} t_n = 2e^n t_0 \\ H = \frac{1}{2} g t_0^2 \end{cases}$$

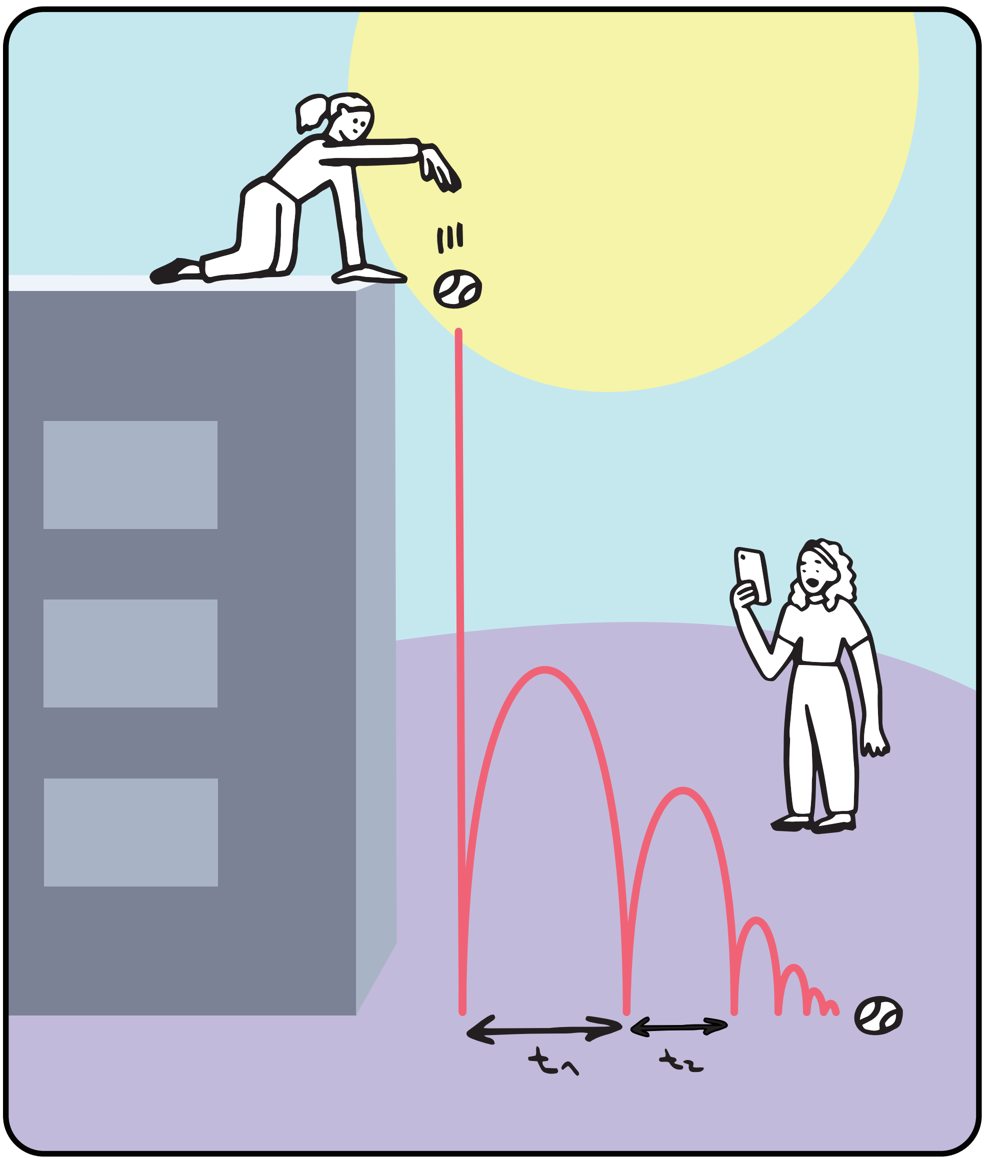
Material

1 ball



Sensor: **camera**

1 smartphone



Drop the ball from the top of the building. Shoot the successive rebounds of the ball to determine the coefficient of restitution (supposed constant) and the duration of rebounds.

t_n = duration of the nth rebound, e = coefficient of restitution, t_0 = duration of the fall from the top of the building, g = 9.8 ms^{-2}

The formula does not consider air drag.

№9. Sound of Bounces

Precision: intermediate

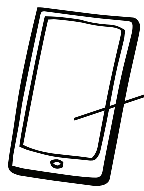
Difficulty: low

Formula

$$\begin{cases} t_n = 2e^n t_0 \\ H = \frac{1}{2} g t_0^2 \end{cases}$$

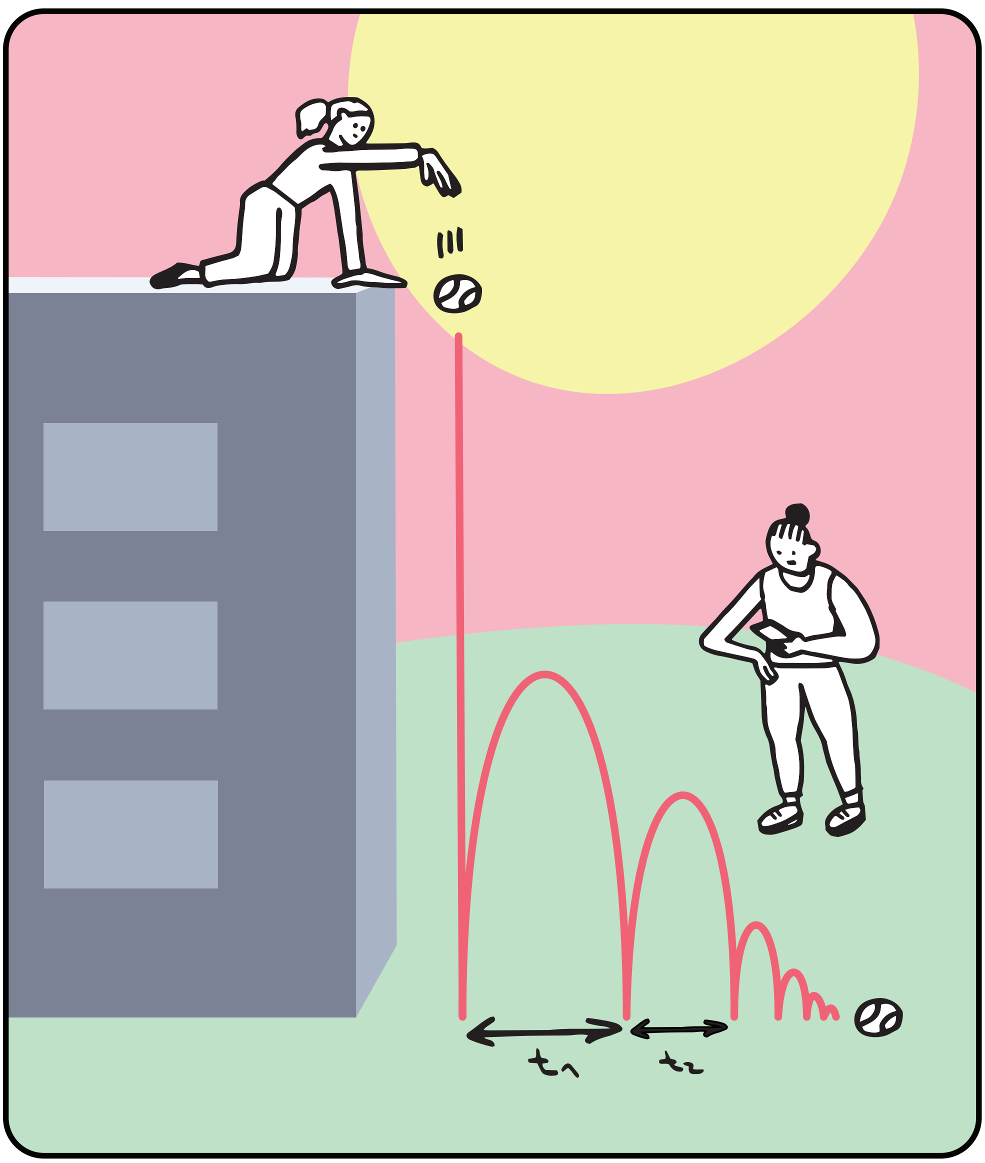
Material

1 ball



Sensor: **microphone**

1 smartphone



Drop the ball from the top of the building. Record the sound of the successive rebounds of the ball to determine their durations (the coefficient of restitution is assumed constant).

t_n = duration of the nth rebound, e = coefficient of restitution, t_0 = duration of the fall from the top of the building, g = 9.8 ms^{-2}

The formula does not consider air drag.

Precision: maximum

Difficulty: intermediate

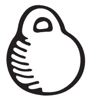
№10. Giant Pendulum Timed

Formula

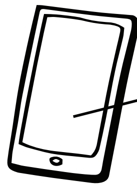
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material

1 long rope

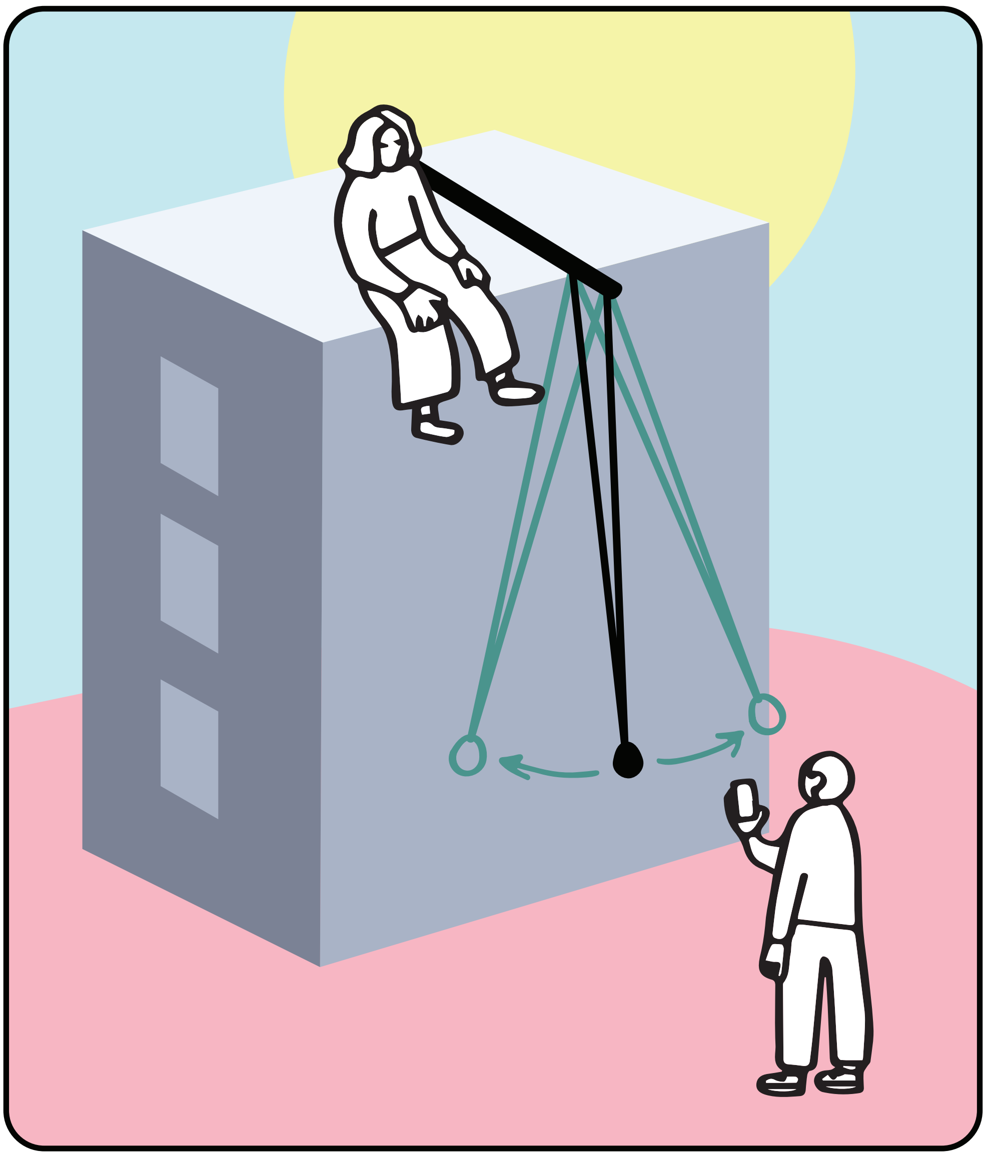


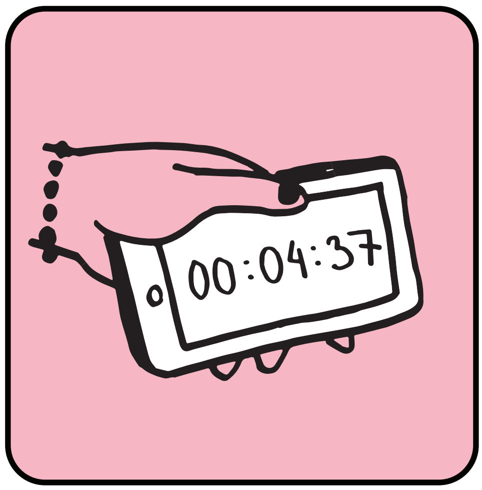
1 mass



Sensor: **stopwatch**

1 smartphone





Make a giant pendulum the size of the building. Use the smartphone timer to determine the period.

T = pendulum period,
g = 9.8 ms^{-2}

The pendulum must not rotate in all directions, it must only swing.

Precision: maximum

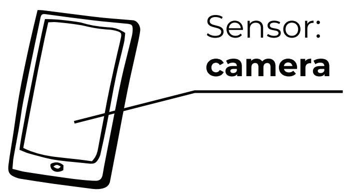
Difficulty: intermediate

№11. Giant Pendulum Filmed

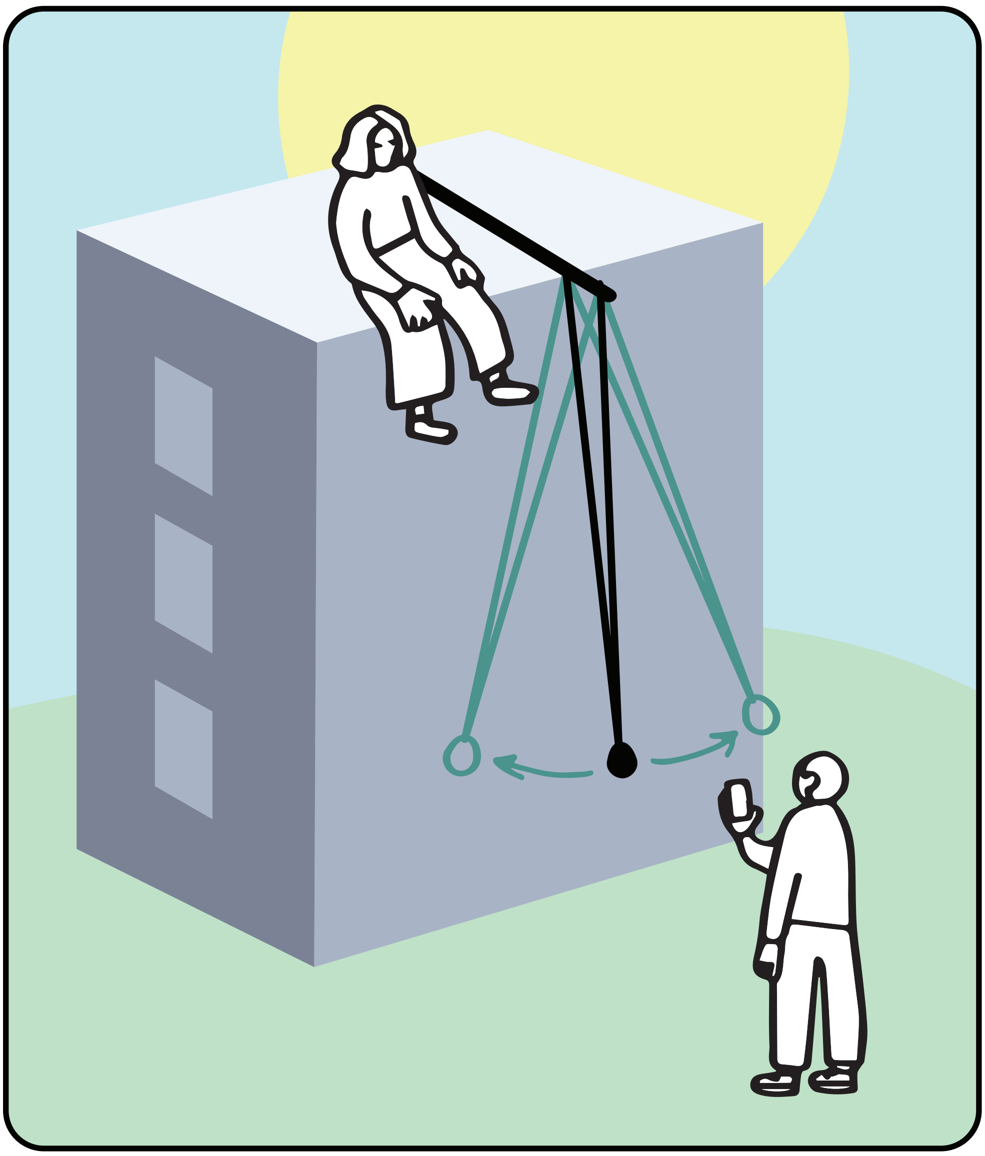
Formula

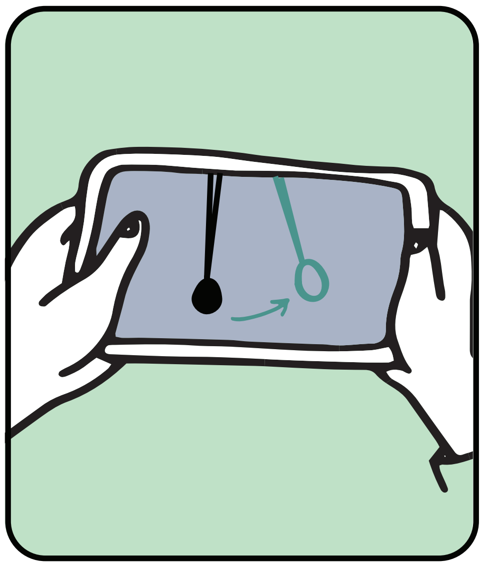
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material



1 smartphone





Make a giant pendulum the size of the building. Film the oscillations of the pendulum to determine the period.

T = pendulum period,
g = 9.8 ms^{-2}

The pendulum must not rotate in all directions, it must only swing.

Precision: low

Difficulty: intermediate

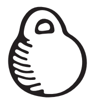
№12. Giant Pendulum & Accelerometer

Formula

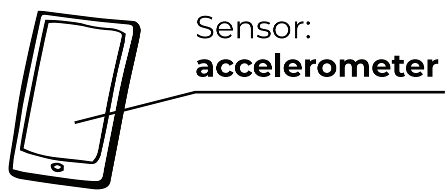
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material

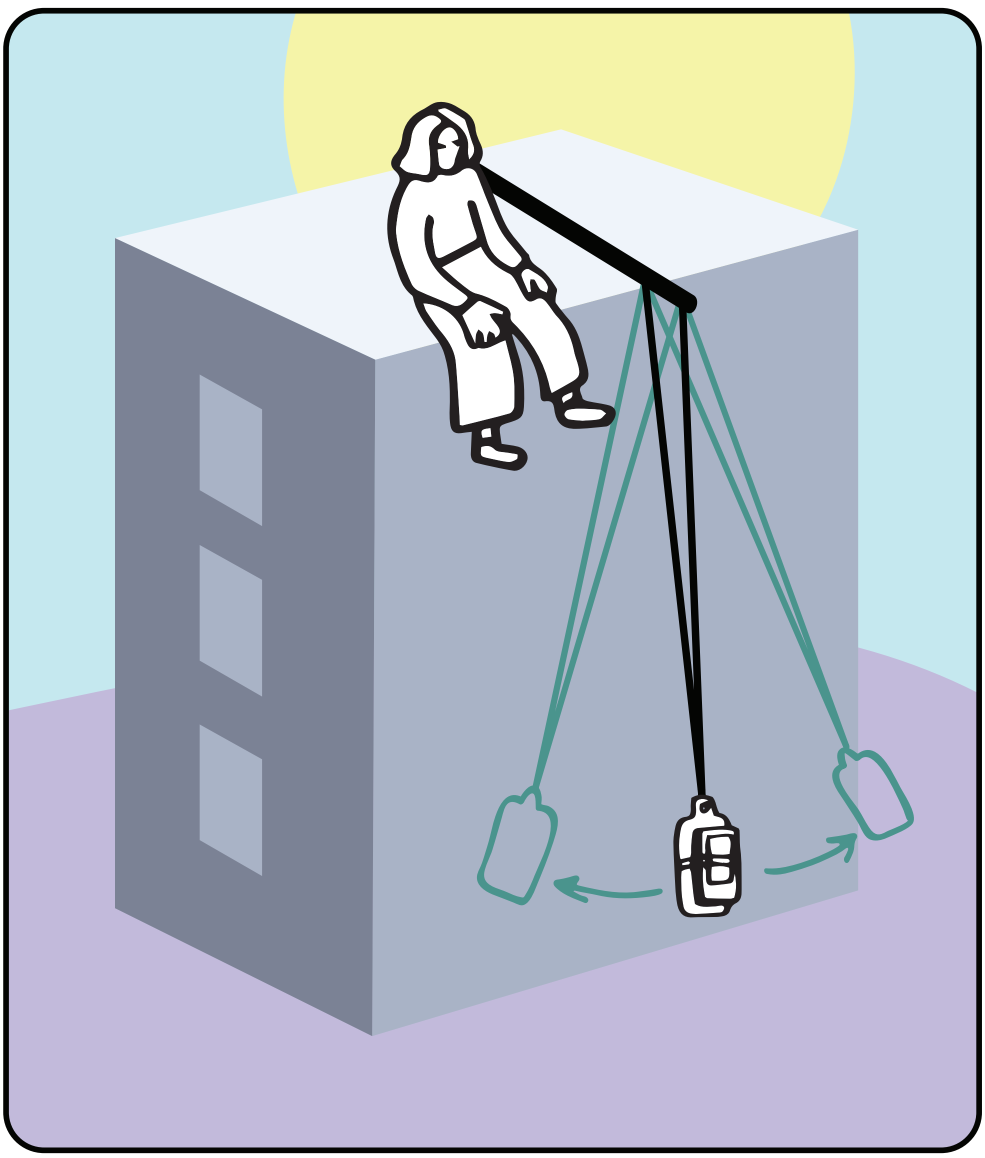
1 long rope



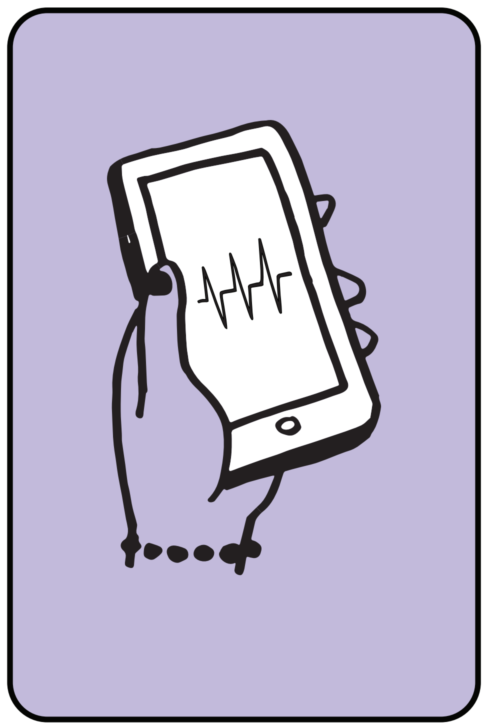
1 mass



1 smartphone



Make a giant pendulum the size of the building. Attach the smartphone to the pendulum, and use the accelerometer to determine the period.



T = pendulum period,
$g = 9.8\ ms^{-2}$

The higher the building, the smaller the acceleration, and the harder the measure will be.

Precision: low

Difficulty: intermediate

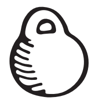
№13. Giant Pendulum & Gyroscope

Formula

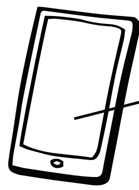
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material

1 long rope

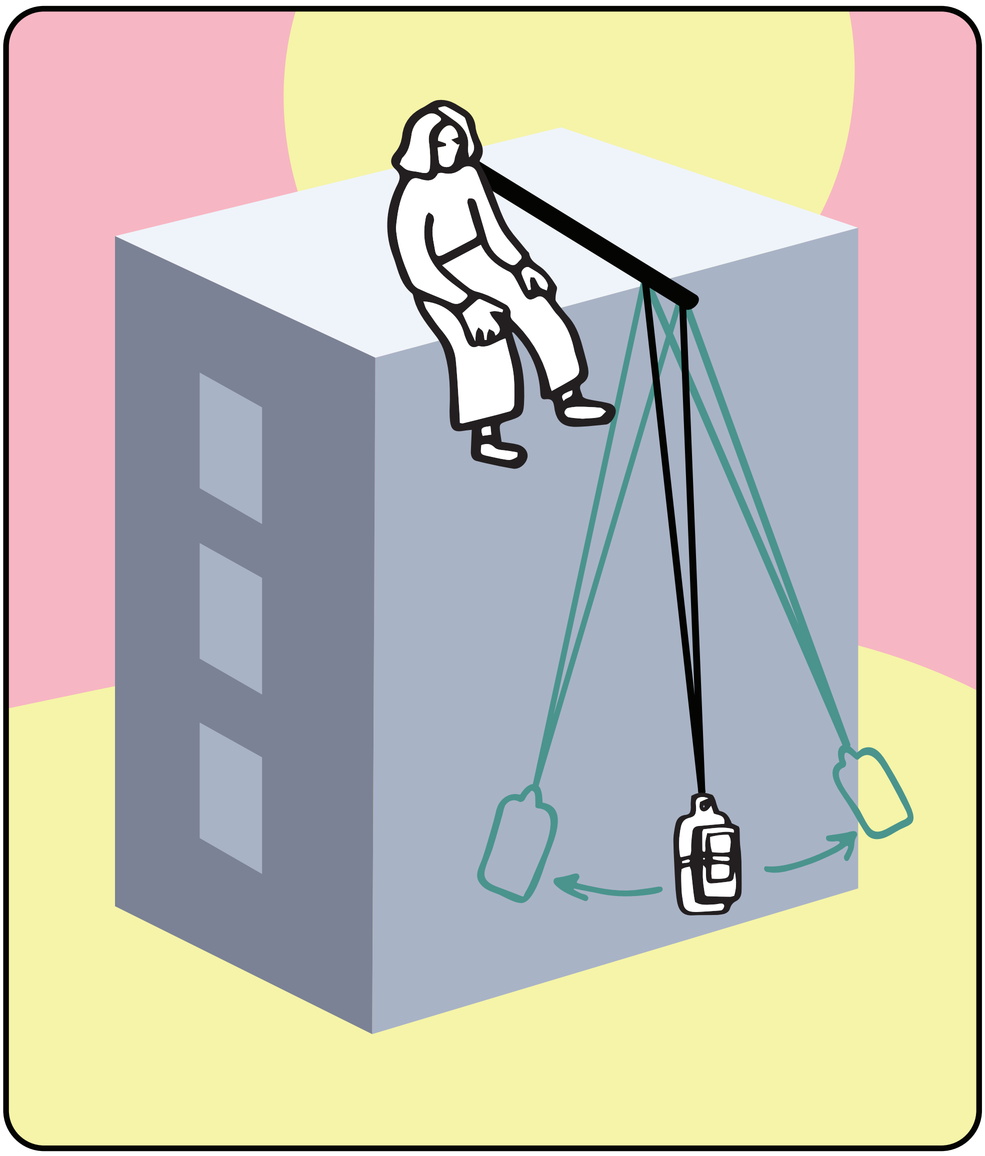


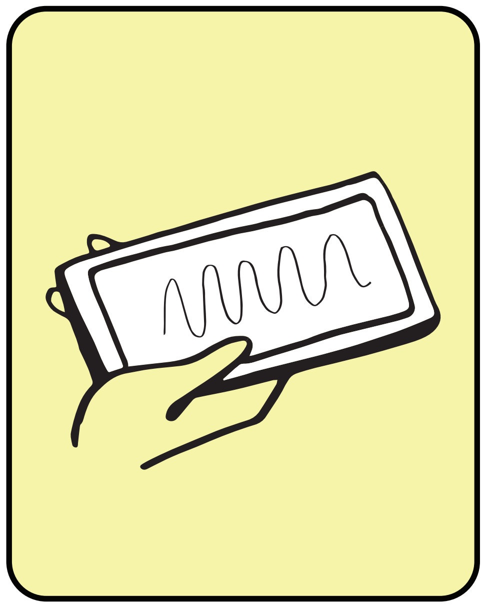
1 mass



Sensor: **gyroscope**

1 smartphone





Make a giant pendulum the size of the building. Attach the smartphone to the pendulum, and use the gyroscope to determine the period.

T = pendulum period,
g = 9.8 ms^{-2}

The higher the building, the smaller the acceleration, and the harder the measure will be.

Precision: high

Difficulty: intermediate

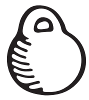
№14. Giant Pendulum & Magnet

Formula

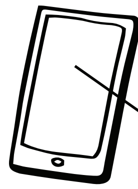
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material

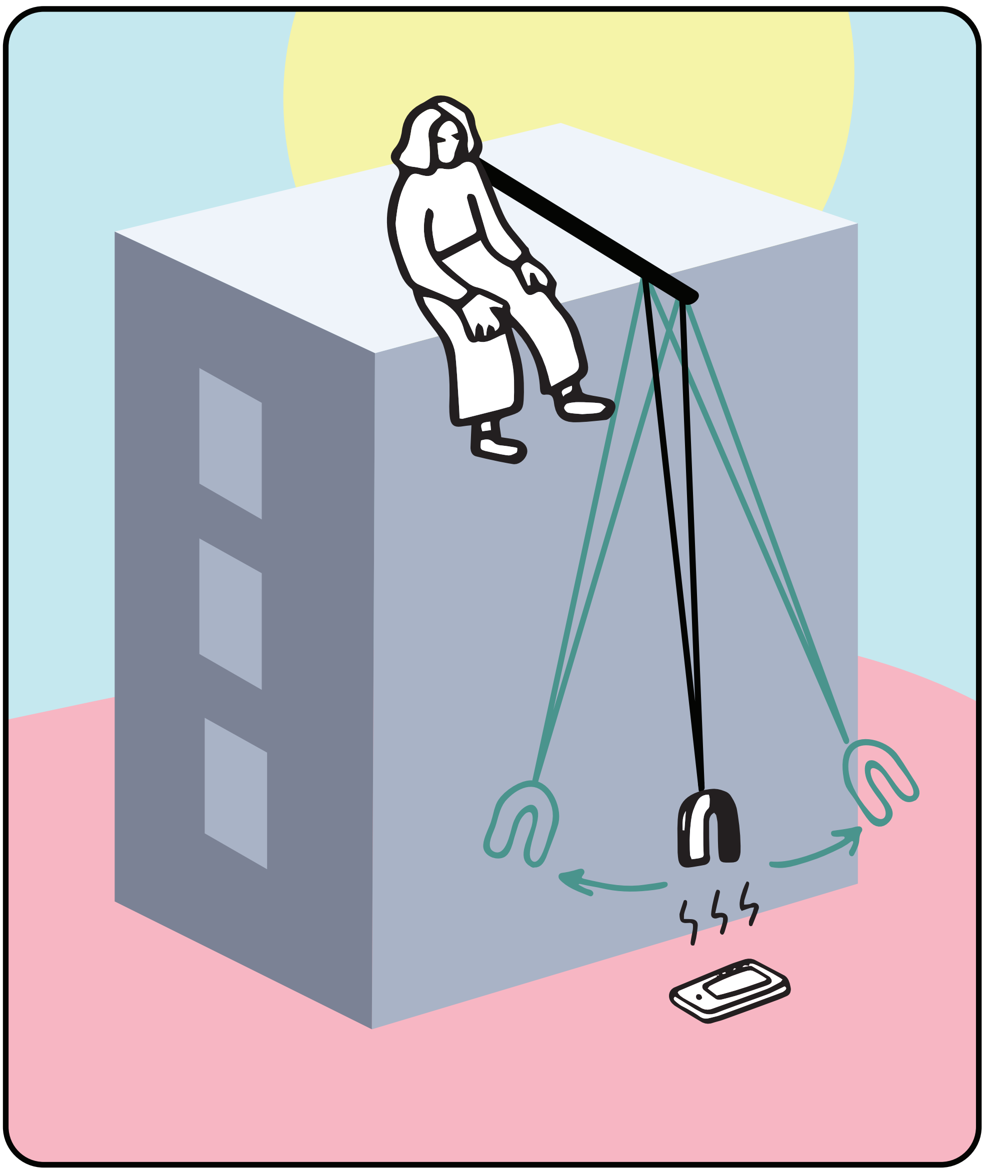

1 long rope

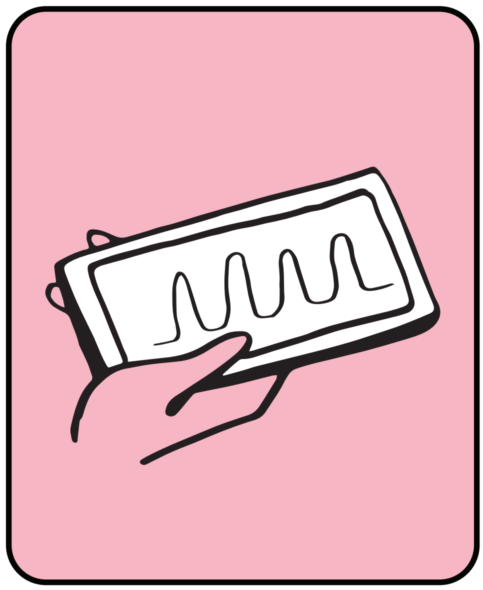

1 mass


1 magnet


Sensor: **magnetometer**

1 smartphone





Make a giant pendulum the size of the building. Attach a magnet to the pendulum. Position the smartphone vertically to detect the passage of the magnet.

T = pendulum period,
g = 9.8 ms^{-2}

The Earth's magnetic field can be used in place of the magnet; the smartphone must then be fixed on the pendulum.

Precision: high

Difficulty: intermediate

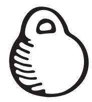
№15. Giant Pendulum & Light

Formula

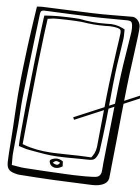
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material

1 long rope

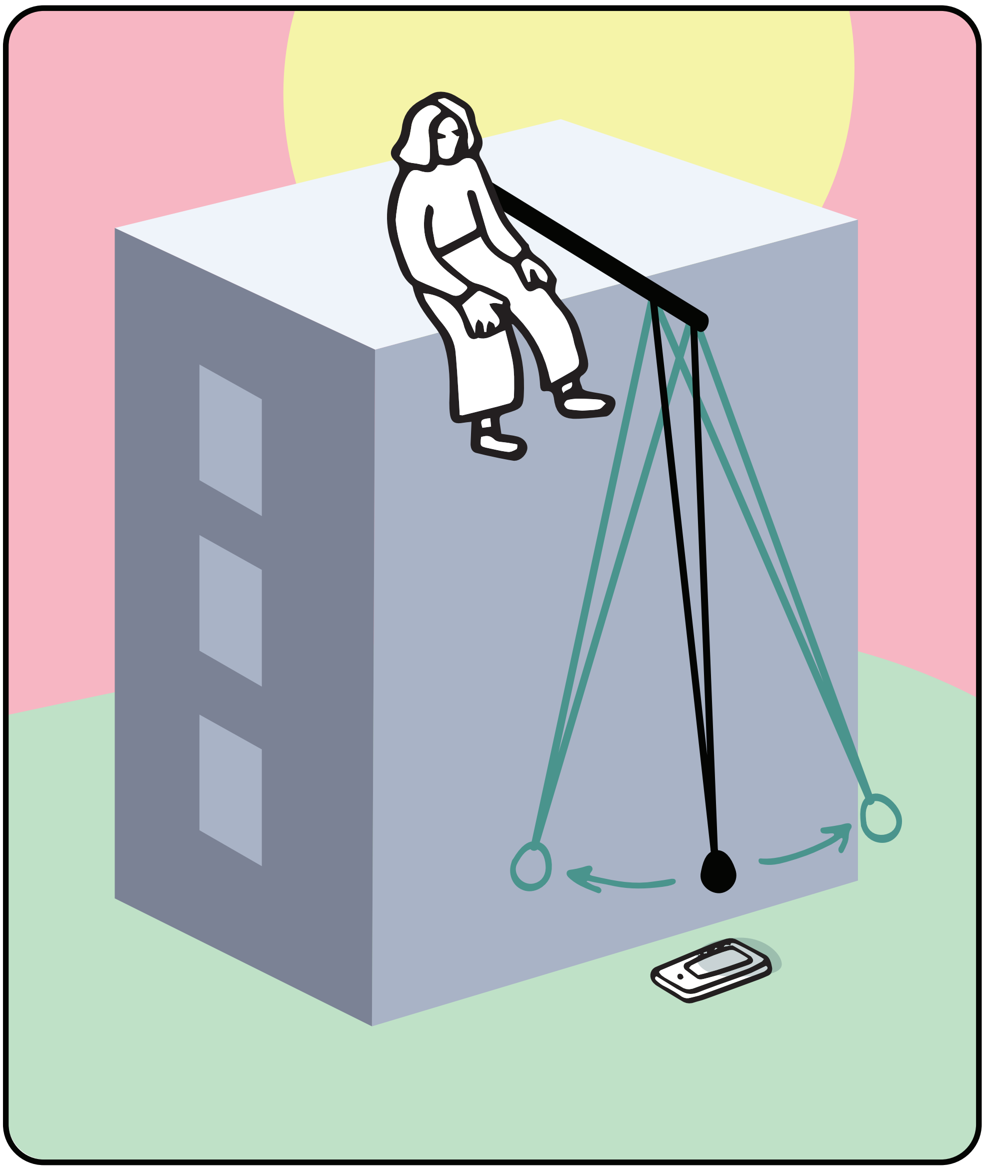


1 mass

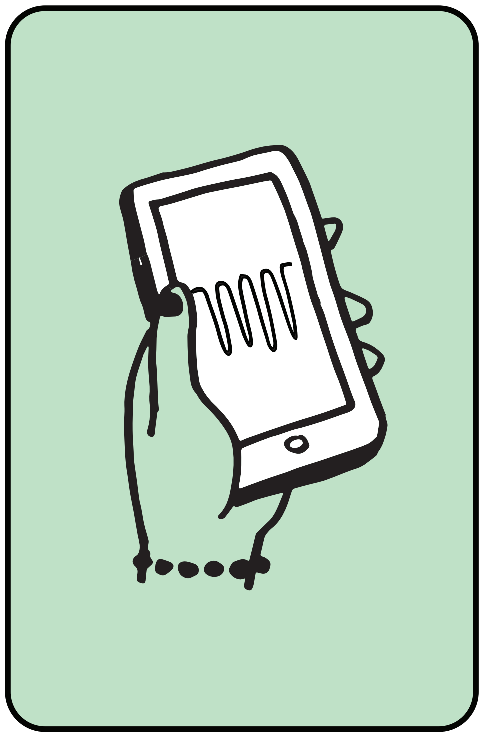


Sensor:
light sensor

1 smartphone



Make a giant pendulum the size of the building. Position the smartphone vertically to detect the shadow of the pendulum.



T = pendulum period,
g = 9.8 ms^{-2}

The pendulum must not rotate in all directions, it must only swing.

Precision: high

Difficulty: intermediate

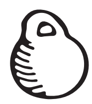
№16. Giant Pendulum by Proximity

Formula

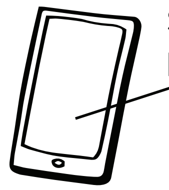
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material

1 long rope

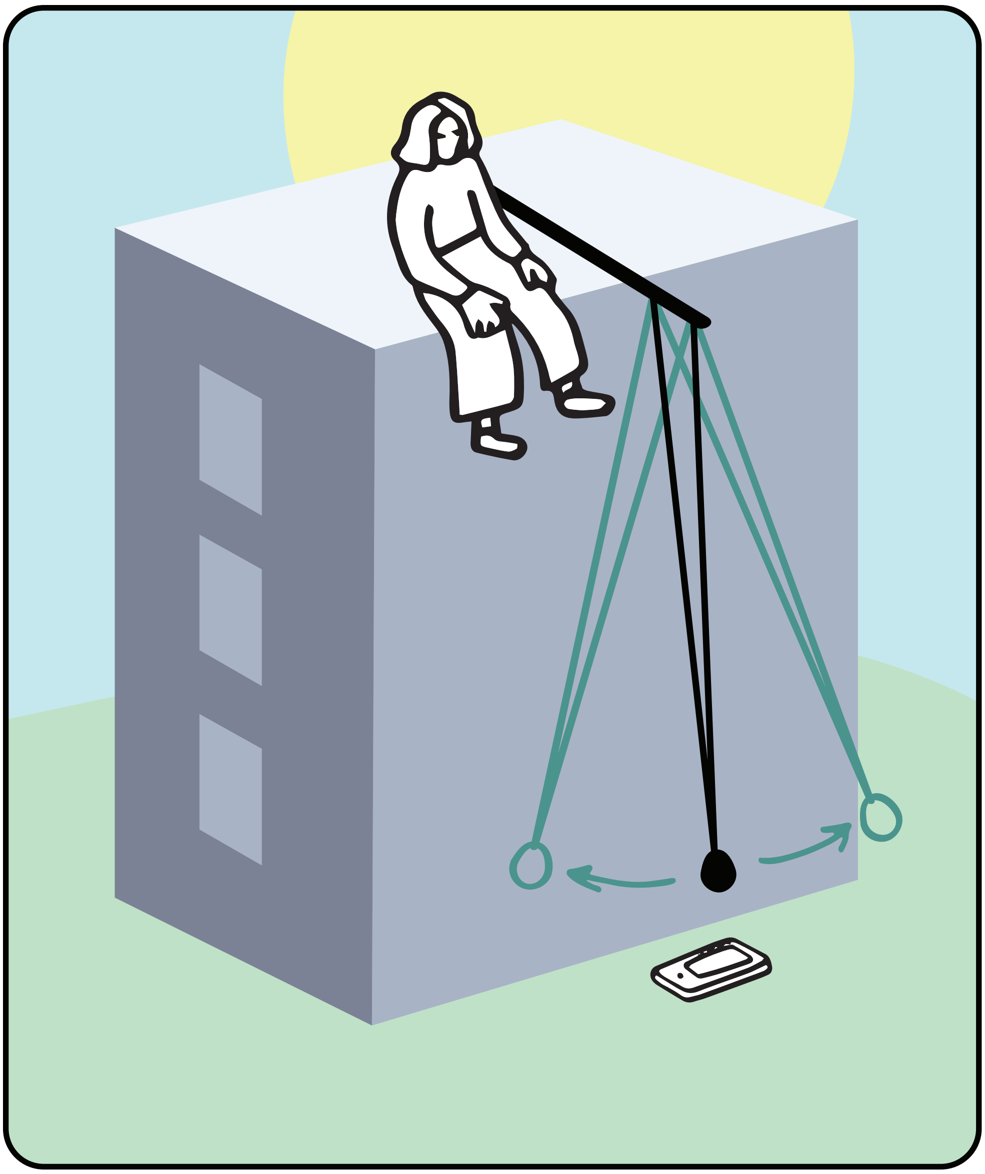


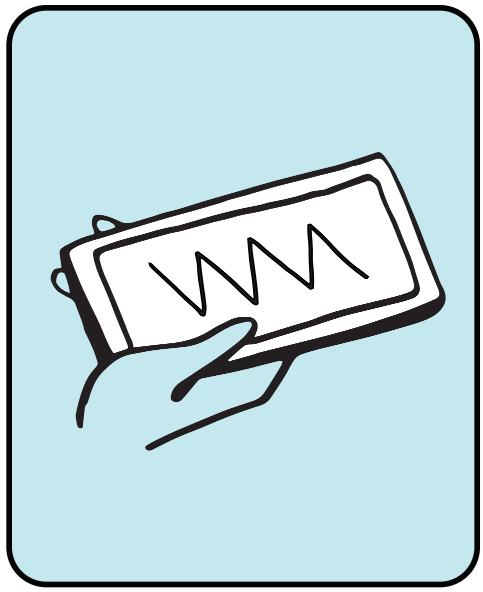
1 mass



Sensor:
proximity sensor

1 smartphone





Make a giant pendulum the size of the building. Position the smartphone vertically, very close to the pendulum to detect its passage.

T = pendulum period,
$g = 9.8\ ms^{-2}$

The pendulum must not rotate in all directions, it must only swing.

Precision: high

Difficulty: intermediate

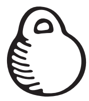
№17. Giant Pendulum with Sound

Formula

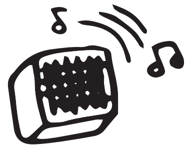
$$H = g\left(\frac{T}{2\pi}\right)^2$$

Material

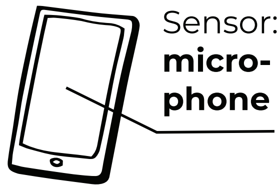
1 long rope



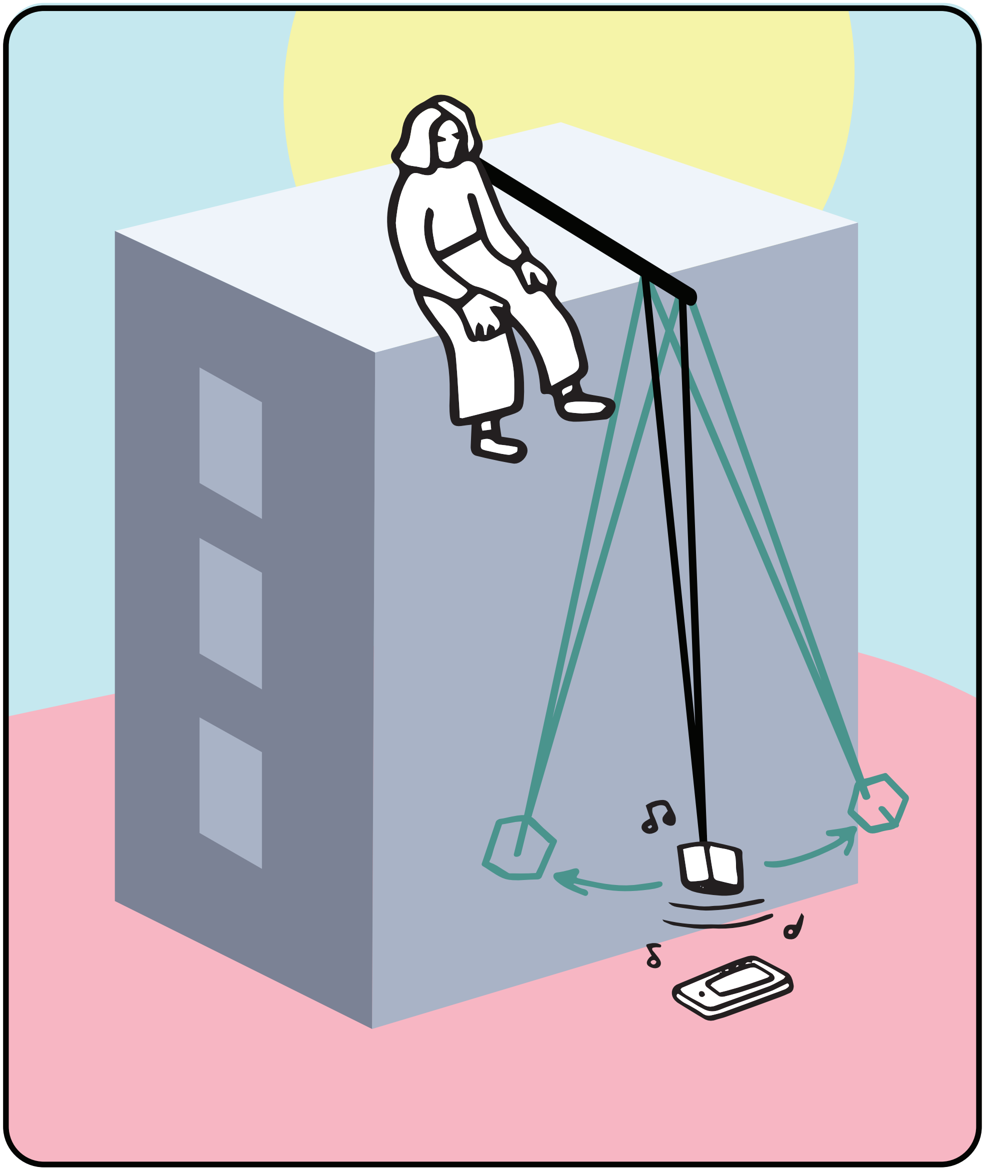
1 mass



1 bluetooth speaker



1 smartphone



Make a giant pendulum the size of the building. Attach the speaker to the pendulum, and send a constant sound. Position the smartphone vertically, and use the variation in the amplitude of the recorded sound to determine the period.

T = pendulum period,
$g = 9.8\ ms^{-2}$

The pendulum must not rotate in all directions, it must only swing.

Precision: low

Difficulty: intermediate

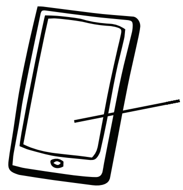
№18. Giant Torsional Pendulum

Formula

$$H \propto T^2$$

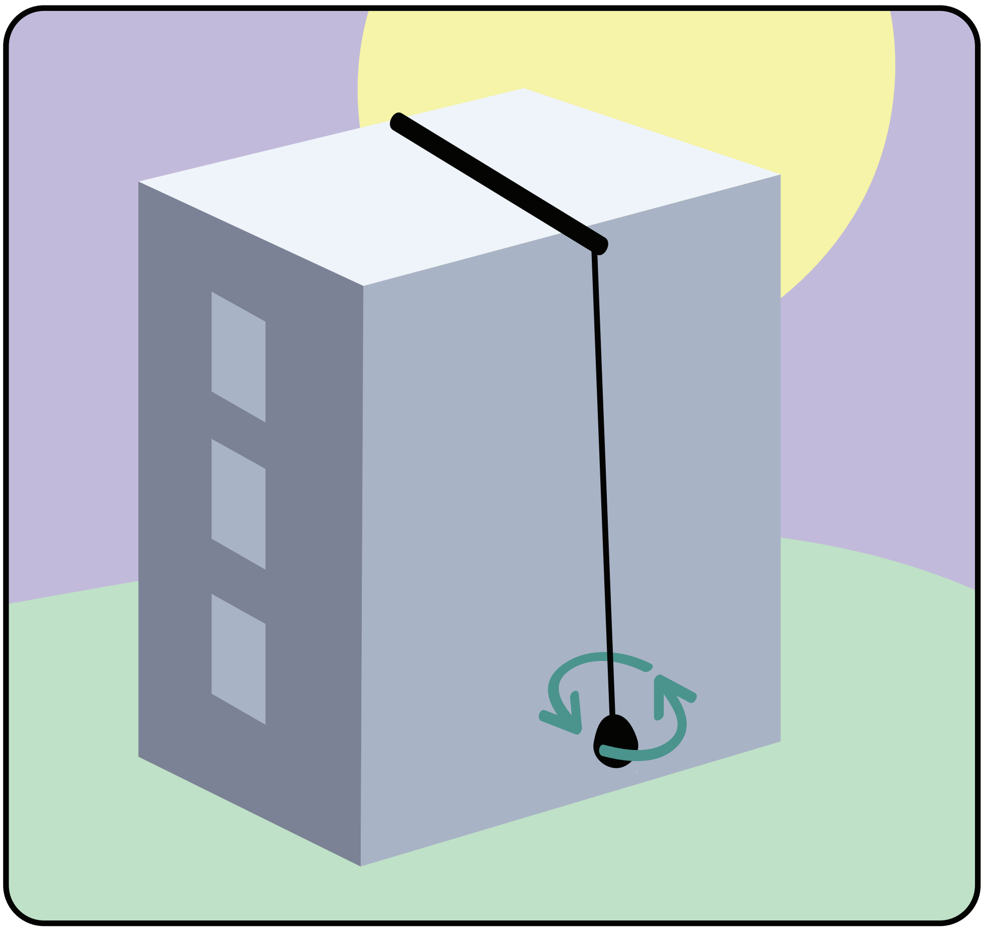
Material

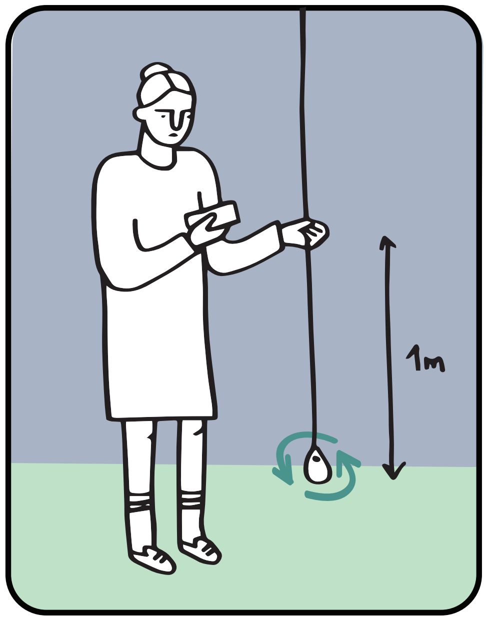
1 long rope



1 smartphone

Sensors:
stopwatch, camera, accelerometer, gyroscope, magnetometer, light sensor, proximity sensor, microphone





Make a giant torsional pendulum the size of the building. Measure the period using one of the giant pendulum methods. Calibrate the torsion constant by measuring the period for a 1 m rope length.

T = pendulum period

Precision: low

Difficulty: high

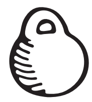
№19. Centripetal Acceleration

Formula

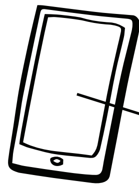
$$H = \frac{a_c}{\dot{\theta}^2}$$

Material

1 longue corde

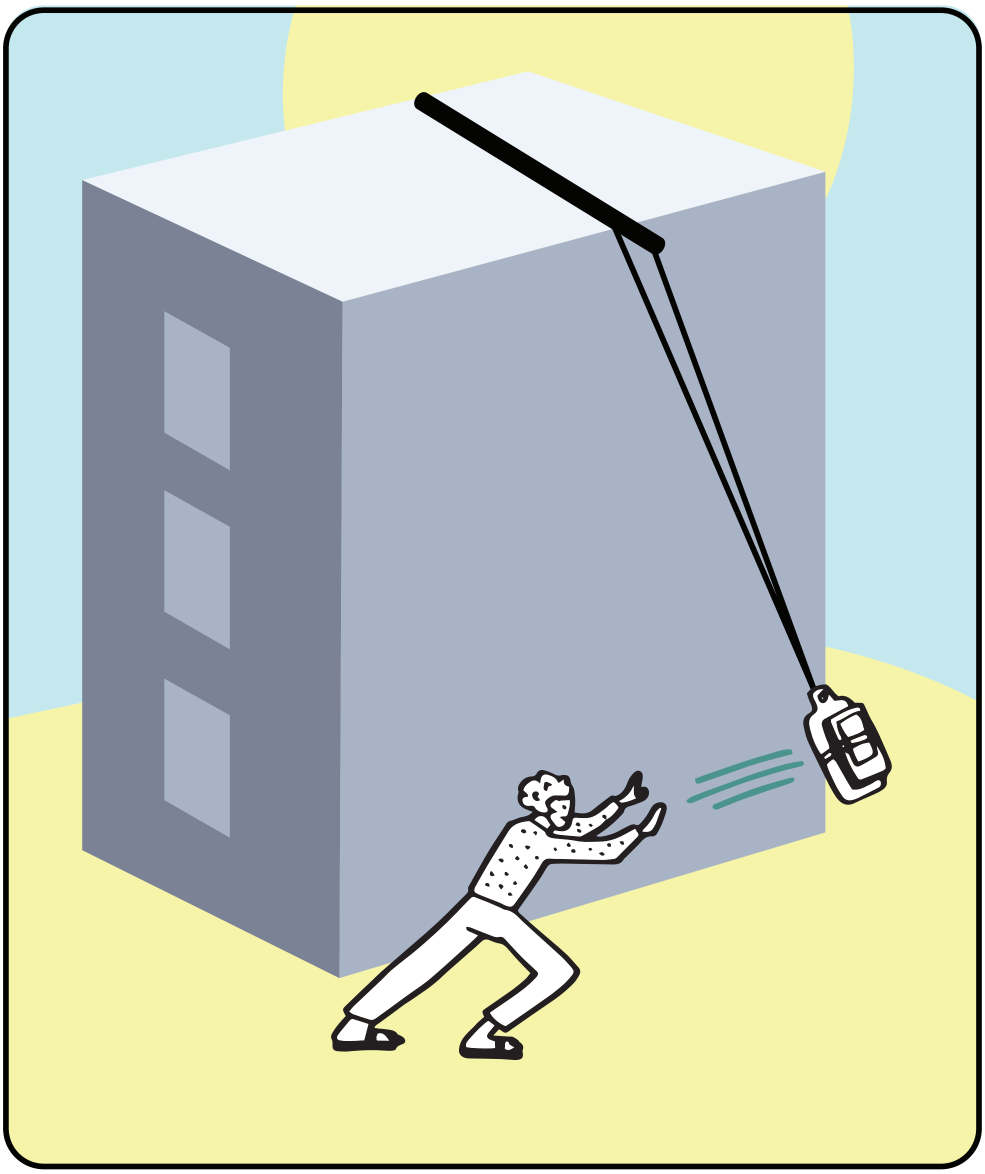


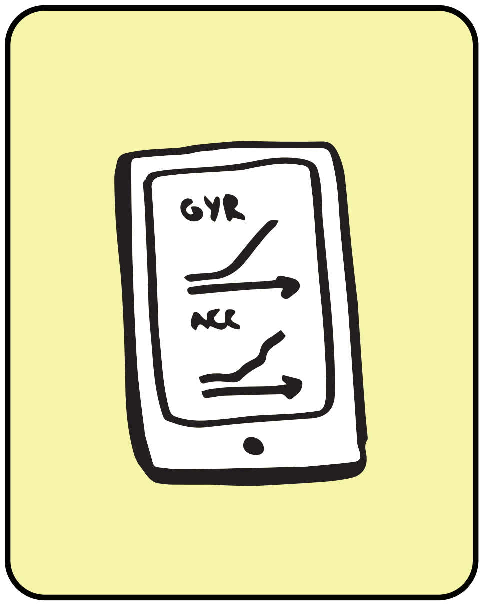
1 mass



Sensors: **accelerometer, gyroscope**

1 smartphone





Make a giant pendulum the size of the building. Attach the smartphone to the pendulum, and use the accelerometer to determine the centripetal acceleration and the gyroscope to determine the angular velocity.

a_c = centripetal acceleration,
$\dot{\theta}$ = angular velocity

The higher the building, the smaller the acceleration, and the harder the measure will be. Throw the pendulum as hard as you reasonably can.

Precision: low

Difficulty: maximum

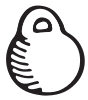
№20. Angular Velocity

Formula

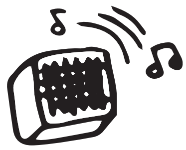
$$H = \frac{v}{\dot{\theta}}$$

Material

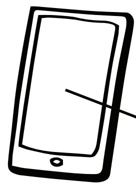
1 long rope



1 mass

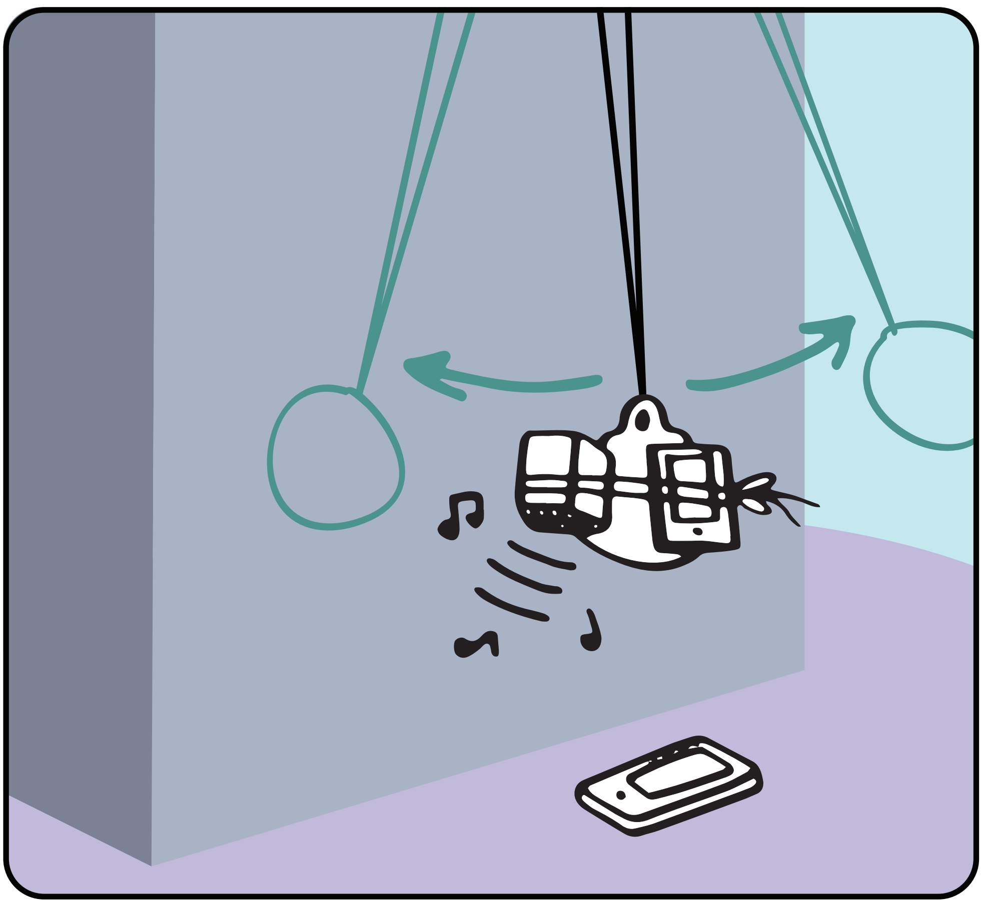


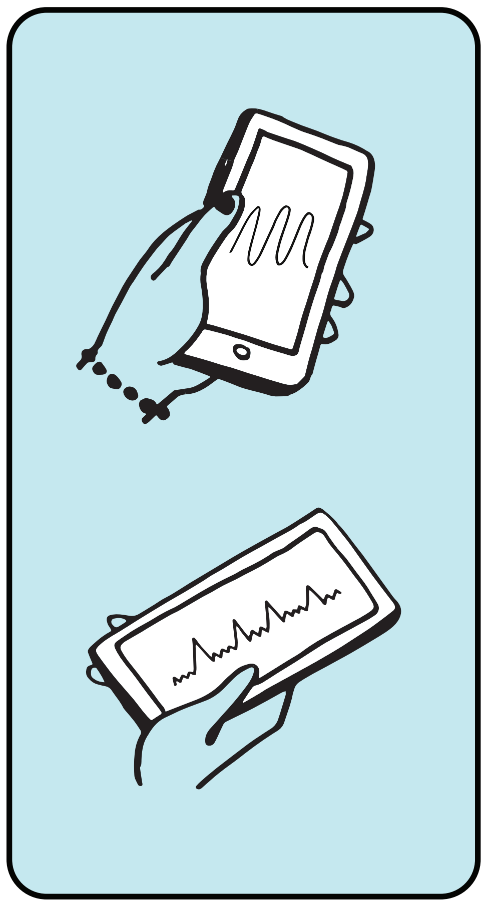
1 bluetooth speaker



Sensors: **microphone, gyroscope**

2 smartphones





v = speed, $\dot{\theta}$ = angular velocity

Make a giant pendulum the size of the building. Attach the smartphone to the pendulum, and use the gyroscope to determine the angular velocity. Attach the speaker to the pendulum, and send a single note. Position the second smartphone vertically, and use the recorded sound to determine the speed of the pendulum by Doppler effect.

Precision: high

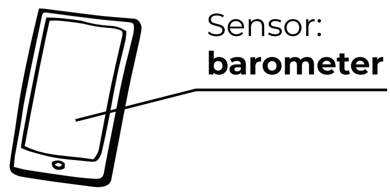
Difficulty: minimum

№36. Pressure Variation

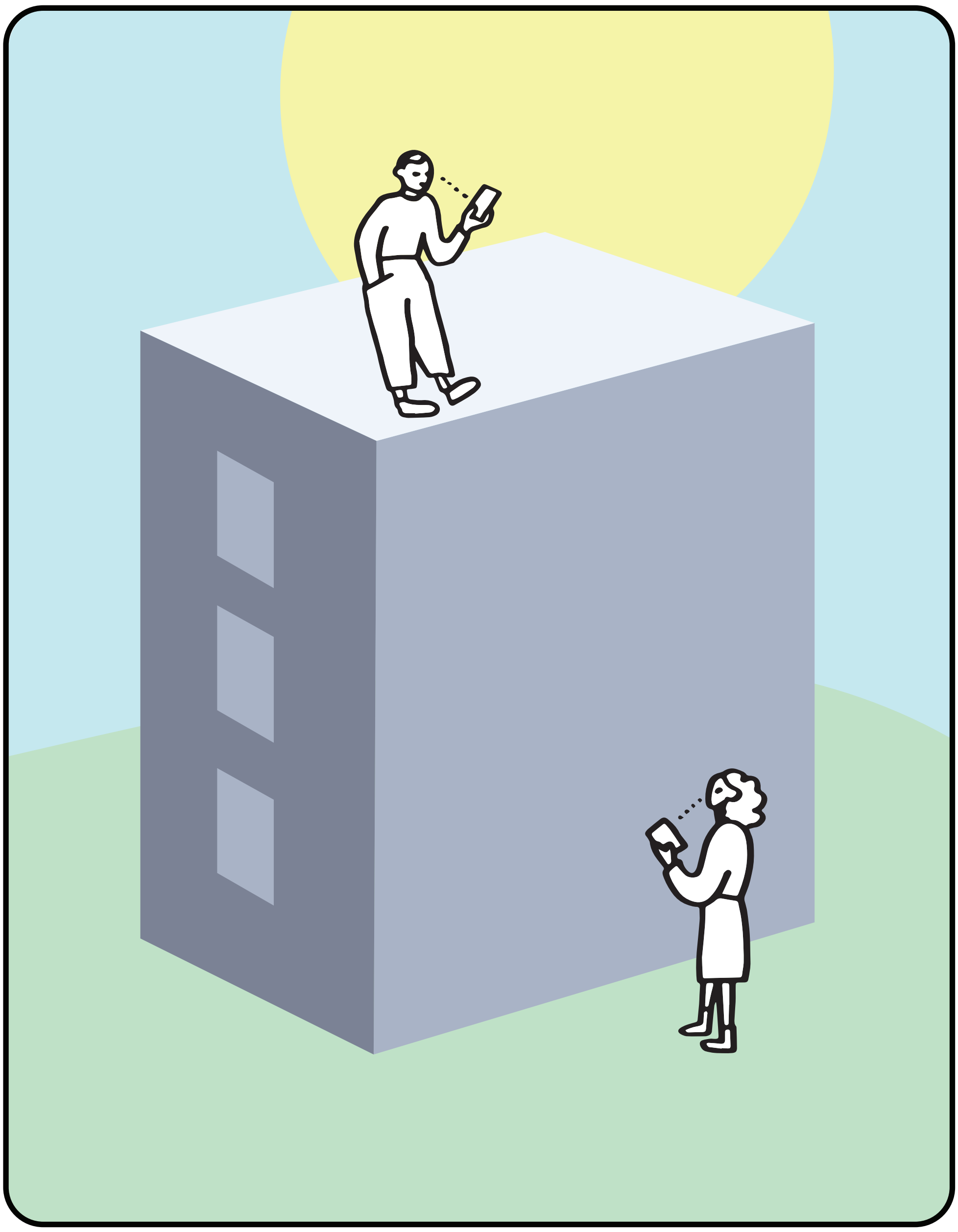
Formula

$$H = \frac{P_2 - P_1}{\rho g}$$

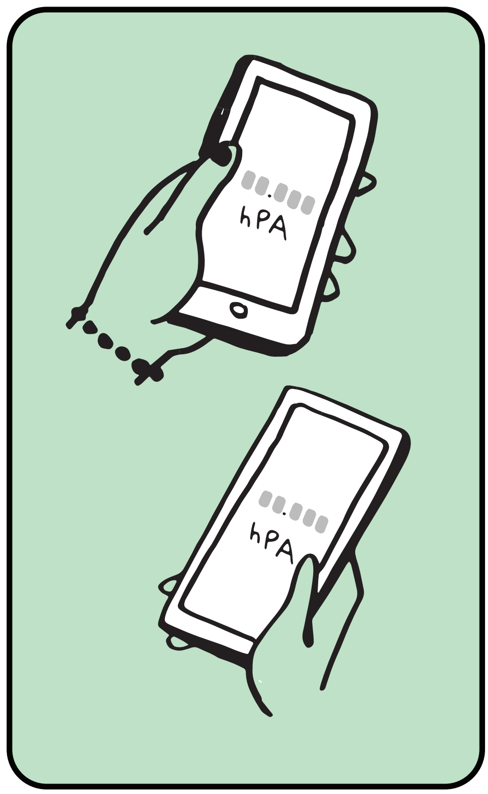
Material



1 smartphone



Measure the atmospheric pressure at the top and bottom of the building. The pressure variation depends directly on the height and density of air.



P_1 = pressure at the top,
P_2 = pressure at the bottom,
ρ = density of air, $g = 9.8\ ms^{-2}$

Precision: high

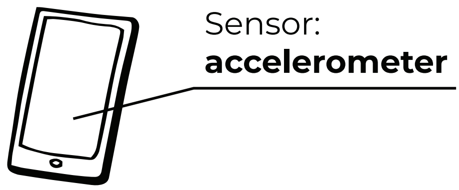
Difficulty: low

№37. Elevator

Formula

$$H = \iint \ddot{z} \, dt$$

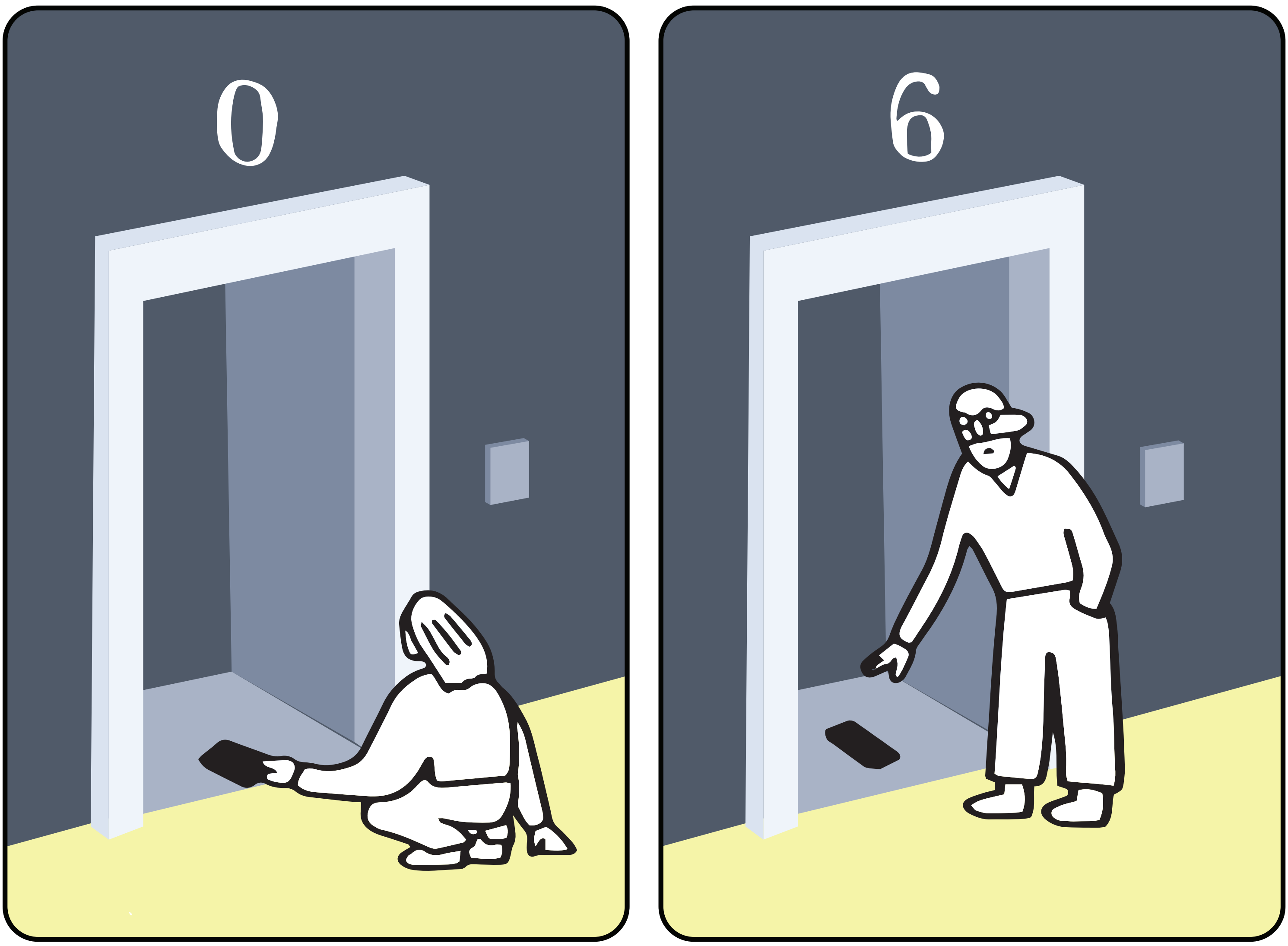
Material



1 smartphone

Lay your smartphone flat in the elevator on the ground floor and then press the top floor button. Integrate the accelerometer measurements twice to obtain the height.

$\ddot{z}$ = vertical acceleration



This project was imagined by Frédéric Bouquet (Paris-Saclay University) and Giovanni Organtini (Sapienza Università di Roma, Italy).

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