TOPIC 1
ESSENTIAL SKILLS AND SUPPORT GUIDES

SUBTOPIC 1.2
TOOL 2: TECHNOLOGY

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Sensors

Sensors, also known as probes, are used in conjunction with data loggers and allow us to measure certain variables such as speed or temperature electronically.

A data logger is a component that has the ability to collect data from sensors and record it in a table or plot it in a graph. It can either be a standalone physical device or one that connects to a computer, but it can also exist as software.

Table 1 lists some examples of variables that can be measured using a data logger, together with the type of sensor/probe used to measure it.

Table 1. Examples of variables measured and the types of probes used.

Variable measured	Sensor/probe used
Temperature	Temperature sensor
Speed/acceleration	Photogate/motion sensor
Force	Force sensor
Voltage/current	Voltage/current sensor
Magnetic field strength	Magnetic field sensor
Gas pressure	Pressure sensor

Figure 1 shows the use of data logging equipment to measure the temperature of water.

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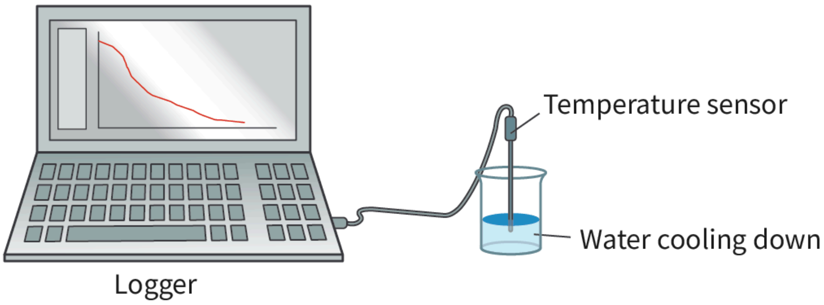

Figure 1. Measuring and logging the temperature of the water in the beaker using a sensor and a data logger software with the use of a computer.

More information for figure 1

The illustration displays a setup for measuring and logging temperature. On the right, a beaker contains water, with a temperature sensor inserted into it. The sensor is connected to a laptop labeled 'Logger' via a cable. The laptop screen shows a graph with a downward-sloping red line, indicating the temperature data being logged as the water cools down. The labels 'Temperature sensor' point to the sensor in the beaker and 'Water cooling down' next to the beaker highlight the setup. This diagram illustrates the process of temperature measurement and data logging using this equipment.

[Generated by AI]

Benefits of using sensors and data loggers in the laboratory

Listed below are some of the main advantages of using sensors and data loggers to measure and record your data.

- Using a sensor connected to a data logger allows you to collect and record large amounts of data. Increasing the size of your data set will increase the reliability of your results. It is also easier to identify outliers from large data sets.
- A sensor and data logger can measure and record variables over a short period of time or over an extended period. For example, if an experiment requires ten measurements per second, it would be impossible to read them with your eyes and record them manually with pen and paper. Equally, if you had to leave an experiment running over several hours, the sensor and data logger would operate effectively and consistently over this time.
- Measurements can be recorded to a greater level of precision when compared to analogue measurement devices (see section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/)). This means that

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the number of decimal places recorded for each measurement is typically greater than that of analogue apparatus.

- Sensors have a reduced possibility of making measurement errors such as parallax errors, such as reading the temperature from an analogue thermometer. This does not mean that random and/or systematic errors are eliminated completely. For example, sensors also need calibration to avoid zero errors. Sensors can also improve accuracy by removing or reducing human factors. For instance, using a sensor such as a motion gate would remove the reaction time discussed when measuring time in section 1.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-digital-equipment-id-48814/).
- Another benefit for using sensors is when the experiment is either inaccessible or hazardous for the measurements to be made in person. This is predominantly the case in nuclear and astrophysics. It is simply not feasible to take measurements inside a nuclear reactor core or on the Mars rover.

For a more thorough analysis of how to deal with errors and uncertainties see sections 1.3.9a (/study/app/math-aa-hl/sid-423-cid-762593/book/recording-data-id-48956/), 1.3.9b (/study/app/math-aa-hl/sid-423-cid-762593/book/errors-and-uncertainties-id-49160/) and 1.3.9c (/study/app/math-aa-hl/sid-423-cid-762593/book/propagation-of-uncertainties-id-49161/).

The type of equipment available to each school will vary, however it is required that you have some experience at using some type of sensors.

Exercise

Click a question to answer

Tool in action

To read more about the skills in this section and see examples of them being used in physics, take a look at the following:

- Section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/) Measuring variables with analogue equipment.
- Section 1.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-digital-equipment-id-48814/) Measuring variables with digital equipment.
- Section 1.4.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/) Practical: Investigating the acceleration of free fall.

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- Section 1.4.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-relationship-between-velocity-id-46751/) Practical: Investigating the relationship between velocity and the horizontal distance travelled by a projectile.
- Section E.4.2a (/study/app/math-aa-hl/sid-423-cid-762593/book/nuclear-power-plants-id-46450/) Nuclear power plants.
- Section E.5.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-distances-in-space-id-46458/) Measuring distances in space.

1. Essential skills and support guides / 1.2 Tool 2: Technology

Collecting data from databases

Some phenomena in physics are more challenging than others to explore experimentally. The first practical challenge can be the scale: physics involves studying objects and processes in the very big scale, such as stars or galaxies, and in the very small scale such as subatomic particles. Another issue is access to equipment that may go beyond the one available at a typical school laboratory.

For such explorations, we need to rely on secondary data which can be found in databases. A database is an organised collection of data, such as measurements from observations and experiments already done.

Reputable science organisations, universities and research laboratories collect data and organise it into databases, which can be accessed and used by other scientists or by the public.

List of databases

The following is a list of databases that contain secondary data. These links should prove useful throughout the DP physics course. This is a non-exhaustive list, meant only to give you some indicative examples. The order is alphabetical.

The CERN Open Data Portal (https://opendata.cern.ch/) contains a range of data produced through the research performed at CERN. It also includes software and documentation needed to understand and analyse the data.

The IAEA Nuclear Data Services (https://www-nds.iaea.org/) database provides a wealth of data regarding atomic and nuclear physics research.

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The NASA Exoplanet Archive (https://exoplanetarchive.ipac.caltech.edu/) is an online catalogue which includes data on exoplanets and stars as well as tools to work on this data.

The SIMBAD Astronomical Database - CDS (Strasbourg) (u-strasbg.fr) (https://simbad.u-strasbg.fr/simbad/). The name is an acronym for Set of Identifications, Measurements and Bibliography for Astronomical Data. It provides various information about stellar objects.

Example of the use of databases in DP physics

In this section, we will look at an example where data from a database is used to answer a research question regarding astrophysics. In this field of physics, many explorations require the use of databases, since direct observations typically require telescopes on the Earth or in space.

A research question could be:

‘Can Hubble’s constant be calculated using data from observations of distances of galaxies and their recessional velocities?’

To do so we will need to use Hubble’s law which states that

$$v = H_0 D$$

where;

- v is the recessional velocity of a galaxy
- D is the distance to the galaxy
- H_0 is the Hubble’s constant

In other words, we expect the velocity and distance to be proportional to each other.

Now that we have a research question, we need to collect the relevant data from a database to answer the question.

Using a data table (https://ned.ipac.caltech.edu/level5/NED05D/ned05D_1.html) from the NASA/IPAC Extragalactic Database listed above. **Table 1** presents the data for five galaxies with positive recessional velocities. The calculation errors are not included.

Table 1. Distance and recessional velocity data for five galaxies.

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Galaxy name	Distance (Mpc)	Recessional velocity (km s^{-1})
IC 5376	68.8	5215
UGC 12901	91.4	7076
UGC 00014	95.8	7455
UGC 12920	101.0	7787
UGC 12897	114.9	8882

Figure 1 plots the data with distance on the horizontal axis and recessional velocity on the vertical axis.

You will learn more about creating data tables and spreadsheets in section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/), how to create graphs in section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/) and how to analyse graphs in section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/).

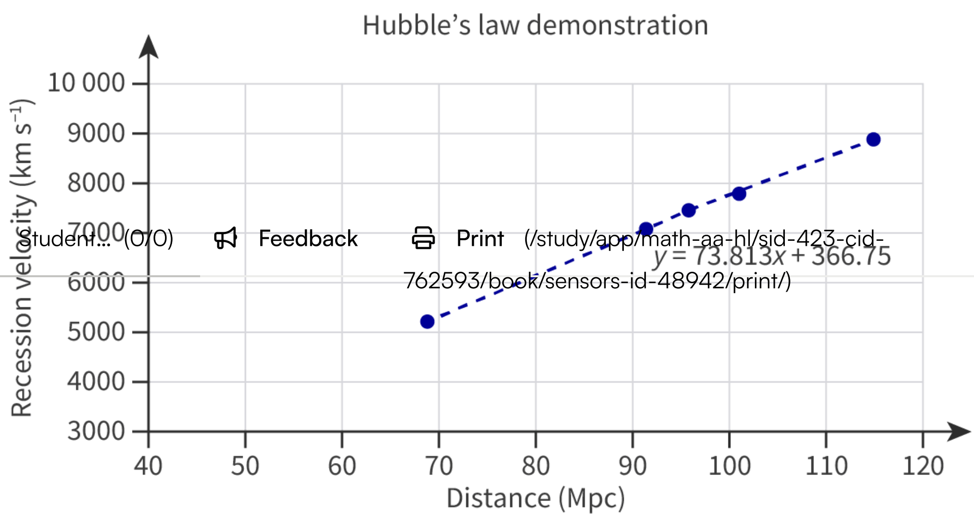

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Figure 1. Plot of distance and recessional velocity for five galaxies.

More information for figure 1

This graph demonstrates Hubble's law, plotting recessional velocity against distance for five galaxies. The X-axis represents the distance in megaparsecs (Mpc), ranging from 40 to 120 Mpc, marked at intervals of 10. The Y-axis represents the recession velocity in kilometers per second (km/s), ranging from 3000 to 10000 km/s, marked at intervals of 1000. Five data points are plotted on the graph, each representing a different galaxy, showing a general trend that as the distance increases, so does the recessional velocity. A dashed line of best

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fit passes through these points, supporting the linear relationship between distance and velocity, described by the equation y = 73.813x + 366.75. This linear relationship indicates that the two quantities are approximately proportional.

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Figure 1 has a line of best fit between the data points showing that the two quantities of distance and recessional velocity are in a good approximation proportional.

Hubble's constant is equal to the gradient of the line of best fit (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/) for how to analyse graphs). We can deduce that according to the data used, Hubble's constant is $H_0 \simeq 74 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

This value is very close to the accepted range of 70 to $73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and demonstrates the research question. Remember that we have not included any uncertainties in this data.

Tool in action

To read more about the skills in this section and see an example of them being used in physics, take a look at the following practical:

- Section 1.4.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-specific-latent-heat-of-vaporisation-of-water-id-46752/) Practical: Measuring the specific latent heat of vaporisation of water.
- Section E.3.3a (/study/app/math-aa-hl/sid-423-cid-762593/book/half-life-id-46544/) Half-life.
- Section E.5.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-hr-diagram-id-46456/) The HR diagram.

1. Essential skills and support guides / 1.2 Tool 2: Technology

Collecting data from models and simulations

In section 1.2.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/collecting-data-from-databases-id-48943/) you saw how you can use databases to gain access to data in situations in which it would be very difficult or even impossible to do so by performing an experiment yourself.

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In such situations, another option is to use simulations or computer models. A simulation is a computer technique that uses software to apply mathematical models to reconstruct and compute the results of a physical process.

Differences between simulations and databases

Databases typically contain data from past or ongoing real life experiments and observations while simulations are virtual representations or models of experiments. As a result, data in databases typically offer results that are considered more reliable.

In simulations you can typically change some parameters and run the virtual experiment again, while in databases the outcomes of the experiments are fixed. This means that simulations are more dynamic and interactive, and you can test a hypothesis repeatedly and at a range of conditions.

Sometimes simulations offer a graphical user interface, a virtual environment that presents the procedure and the results, in real time or at a user-friendly pace. This means that you can use a simulation not just to extract data but also to gain insight into how a phenomenon works.

Simulations taking place in research can be very sophisticated. However, you can also create your own simulation just using your knowledge and some software.

Useful simulations

Through your IBDP physics course you may be asked to use simulations both to enhance your understanding and/or to extract data when practical work in the lab is not possible.

Here you can find a list of some indicative free online sources for physics simulations.

- PhET Interactive Simulations (https://phet.colorado.edu/)
  This website from the University of Colorado Boulder provides many interactive simulations for all main topics of physics.
- GeoGebra tools and resources (https://www.geogebra.org/)
  This is a powerful mathematical tool that can be used to run simulations that users have created, or create your own.
- The Physics Classroom (https://www.physicsclassroom.com/Physics-Interactives)
  A collection of interactive simulations on various physics topics. It also includes some discussion on the theory behind those simulations.
- Javalab - Science simulations (https://javalab.org/en/)
  This platform offers free interactive science simulations, written in Javascript.

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- Concord Consortium STEM Resource Finder (https://learn.concord.org/)
  Collections of resources and activities such as virtual labs and hands-on digital tools.
- LabXchange (https://www.labxchange.org/library?t=SubjectArea%3APhysics&t=ItemType%3Asimulation&page=1&size=24&order=relevance)
  This is a library that contains simulations from PhET and the Concord Consortium (both previously on the list) in a user-friendly environment. You can always also access the source websites directly.

Tool in action

To read more about the skills in this section and see examples of them being used in physics, take a look at the following:

- Section A.1.4b (/study/app/math-aa-hl/sid-423-cid-762593/book/activity-projectile-motion-id-44301/) Activity: Projectile motion.
- Section B.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/what-are-ideal-gases-id-44290/) What are ideal gases?
- Section 1.4.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-an-ideal-gas-law-id-46508/) Practical: Investigating an ideal gas law.
- Section B.5.5a (/study/app/math-aa-hl/sid-423-cid-762593/book/cells-and-internal-resistance-id-44367/) Cells and internal resistance.
- Section 1.4.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-internal-resistance-of-a-cell-id-46512/) Practical: Measuring the internal resistance of a cell.
- Section D.2.3b (/study/app/math-aa-hl/sid-423-cid-762593/book/activity-capacitors-id-46478/) Activity: Capacitors.
- Section E.1.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/atoms-and-photons-id-46593/) The nucleus and atomic energy levels.
- Section E.2.1c (/study/app/math-aa-hl/sid-423-cid-762593/book/activity-compton-scattering-simulation-hl-id-47370/) Activity: Compton scattering simulation (HL).

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Manipulating and representing data

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Using spreadsheets to manipulate data

Researchers often generate a lot of raw data, and technology in the form of spreadsheets could be used to analyse this data. Spreadsheets can be used in multiple ways:

- to organise data into rows and columns
- to perform calculations using formulae
- to sort the data to identify trends or even filter to view specific data.

In the example given in section 1.2.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/collecting-data-from-databases-id-48943/) you could use the correlation coefficient to measure the relationship between the two variables being studied. In a spreadsheet, the formula =CORREL (array1, array2) where array1 stands for the distance to the galaxy (Mpc) and array2 for the recessional velocities of the galaxies gives the correlation coefficient.

Worked example 1

A student wished to investigate how the radius of a sphere affects its terminal velocity while falling through a liquid.

An experiment is set up in which a small metal sphere of radius *r* is released at the top of a glass cylinder placed vertically and filled with a liquid substance (**Figure 1**).

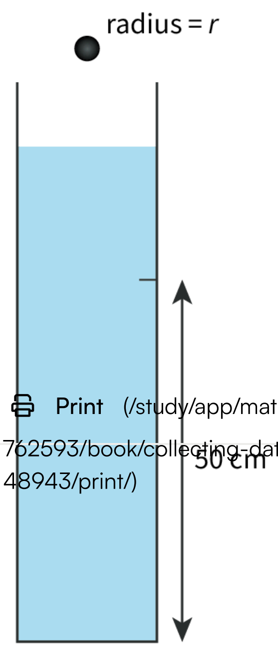

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Figure 1. Experimental setup.

Student view

Once the ball falls through the liquid, a stopwatch is used to measure the time it takes for the ball to fall through the final 0.50 m (50 cm) of the cylinder. Once the ball hits the bottom, the time taken is recorded on a table.

Different spheres with different radii are used. Three trials are performed with each sphere.

Table 1. Raw data collection table.

r (mm)	Recorded time (s)		
	Trial 1	Trial 2	Trial 3
1.00	12.82	12.22	13.23
2.00	3.25	3.31	3.02
3.00	1.48	1.54	1.37
4.00	0.83	0.88	0.72
5.00	0.51	0.63	0.48

1. Calculate the mean average time and record it in an additional column, as shown in **Table 2.**

   Estimate the uncertainty in the calculated mean time. For the uncertainty you may use the formula given below:

$$\text{time uncertainty} = \frac{\text{maximum time} - \text{minimum time}}{2}$$

   Write the calculated values to an appropriate number of significant figures.

   See section 1.3.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/measures-of-central-tendency-id-48951/) to learn more about mean and average values, section 1.3.9a (/study/app/math-aa-hl/sid-423-cid-762593/book/recording-data-id-48956/) for significant figures and section 1.3.9c (/study/app/math-aa-hl/sid-423-cid-762593/book/propagation-of-uncertainties-id-49161/) for estimating uncertainties.

Table 2. Data with mean (average) and uncertainty calculated values.

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r (mm)	Recorded time (s)			Mean time	Uncertainty
	Trial 1	Trial 2	Trial 3	$\frac{t}{s}$	$\frac{\Delta t}{s}$
1.00	12.82	12.22	13.23	**12.7**	**0.5**
2.00	3.25	3.31	3.02		
3.00	1.48	1.54	1.37		
4.00	0.83	0.88	0.72		
5.00	0.51	0.63	0.48		

2. **Figure 2** plots the data on a scatter graph. The first point has been plotted for you, along with bars to represent the uncertainty in measuring the time period. See section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/) to learn more about uncertainty bars.

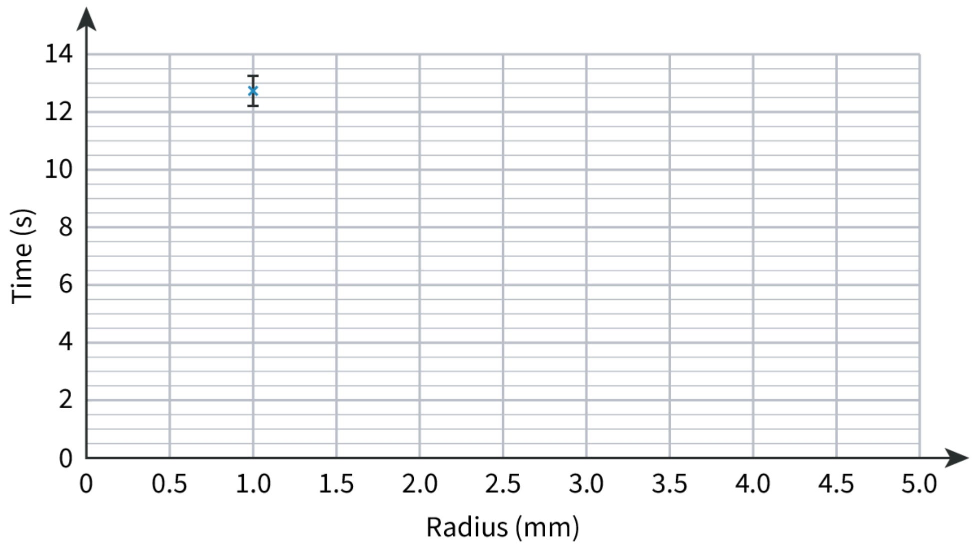

Figure 2. Plot the data on a scattergraph.

More information for figure 2

The image is a scatter graph with the X-axis representing the radius in millimeters (mm) and labeled from 0 to 5. The Y-axis represents time in seconds (s), ranging from 0 to 14. There is one data point plotted on the graph at approximately 1 mm on the X-axis and 12.5 seconds on the Y-axis. There are also bars that represent the uncertainty in measuring the time period. The background features a grid, which helps in determining the values of the points plotted.

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3. Analyse the trends that may emerge. You will learn more about trends in graphs in section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/).

Representing data in a graphical form

The data generated is often represented in the form of scatter graphs. Graphs help to provide a quick visual summary of the data generated. Graphs could be drawn by hand or by using technology. For example, most spreadsheets have a built-in function to generate graphs.

You will learn more about creating graphs in section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/) and how to analyse graphs in section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/).

Tool in action

To read more about the skills in this section and see examples of them being used in physics, take a look at the following:

- Section 1.4.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/) Practical: Investigating the acceleration of free fall.
- Section 1.4.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-relationship-between-velocity-id-46751/) Practical: Investigating the relationship between velocity and the horizontal distance travelled by a projectile.
- Section 1.4.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-an-ideal-gas-law-id-46508/) Practical: Investigating an ideal gas law.
- Section B.5.5b (/study/app/math-aa-hl/sid-423-cid-762593/book/activity-emf-and-internal-resistance-id-44368/) Activity: emf and internal resistance.
- Section C.5.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/nvestigation-id-45343/) Investigation.
- Section E.2.1c (/study/app/math-aa-hl/sid-423-cid-762593/book/activity-compton-scattering-simulation-hl-id-47370/) Activity: Compton scattering simulation (HL).

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Image analysis

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Have you ever wondered how many images you look at each day? Our world is increasingly media-driven so images are found everywhere. To make sense out of them, you constantly process the visual information they give you. In the context of the syllabus, this task is known as image analysis. In simple terms, you perform image analysis by looking into an image, examining it, identifying objects or patterns of interest in order to understand what you see.

For example, astrophysicists analyse images from telescopes and identify objects that appear in them, such as galaxies (**Figure 1**).

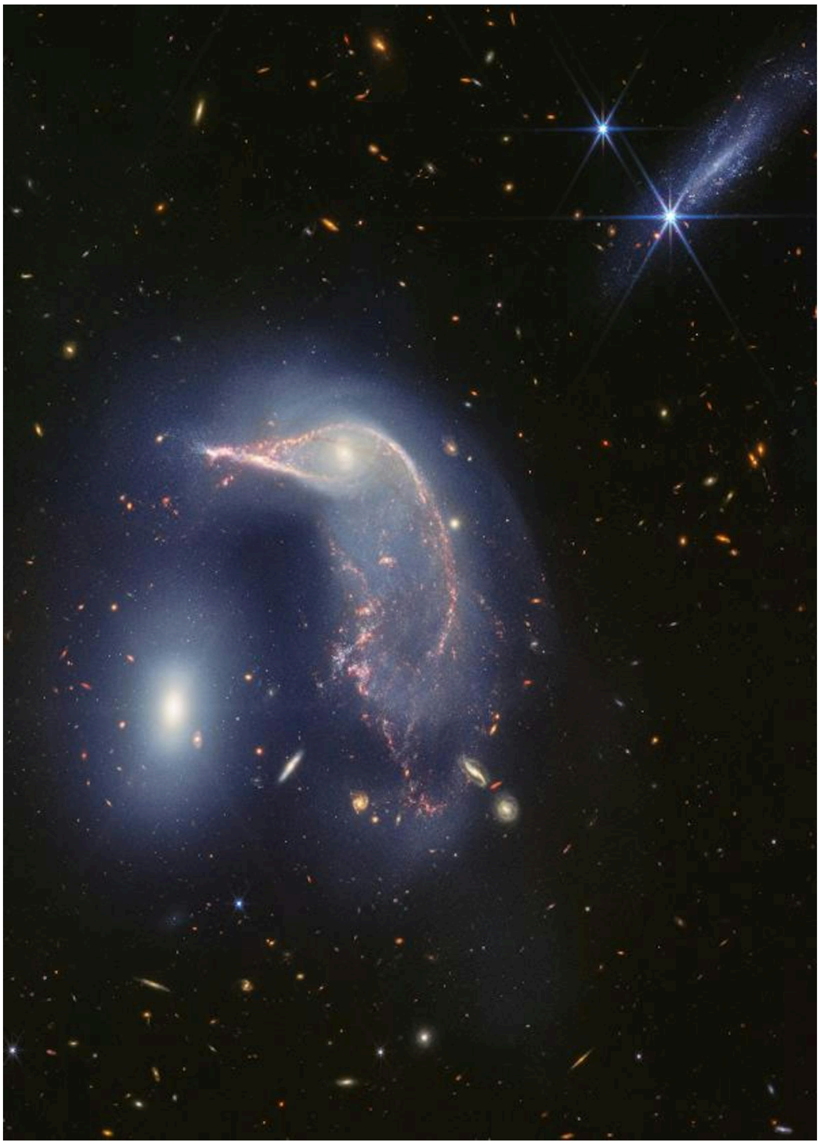

Figure 1. Image from the James Webb Space Telescope showing two interacting galaxies. The pair is known as Arp 142.
Credit: NASA and the Space Telescope Science Institute STScI

Image analysis is particularly important when dealing with observations of experiments. In such circumstances, the data is embedded in the images. By analysing the image, you will be able to extract the data and process it, in order to gain valuable insight.

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Image analysis is a broad term. It employs a variety of methods and is used in many different disciplines. This is indicative of how powerful and useful it can be.

The most common types of image analysis are detailed below. Each type of analysis is accompanied by relevant examples to make the points as clear as possible.

Image classification

This is a high-level analysis of an image. You need to look at an image as a whole and categorise it. Sometimes, it is rather simple to decide what you see in it. In **Figure 2** you can see an image of a galaxy next to an image of a formation in the water of an ocean known as a whirlpool. They have some resemblances, but it is quite clear that they represent different things. Can you determine which image is a whirlpool galaxy and which is a whirlpool in the sea?

(a)

Credit: Steven Robinson Pictures, Getty Images

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(b)

Credit: RelaxFoto.de, Getty Images

Figure 2. Can you identify these two images?

Figure 2a is a whirlpool galaxy called M51a.

Figure 2b is a whirlpool in Saltstraumen, Norway created by strong tidal currents.

This task can also become more tricky. However, the context of an image can always help you categorise it. Have a look at the following example in **Figure 3**: do you see an image of a brain or a sea coral?

Figure 3. Is this a brain or coral?

Credit: Humberto Ramirez, Getty Images

Although the resemblance to a brain is remarkable, the surrounding elements (the context) such as the sand, the lighting and the other formations hint towards the bottom of a sea, where a coral is found.

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Object and pattern recognition

Having identified the classification of an image, you often also need to focus on more specific features of it. This means that you now try to identify specific formations in an image which resemble known objects. For example, medical doctors use this skill very often to identify a

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fracture in a bone. Try to do this yourself in the X-ray in **Interactive 1** – use the slider to check if you're right.

Rights of use

Interactive 1. A Fractured Bone in an X-ray Image.

More information for interactive 1

A slider-based interactive image allows users to explore through an X-ray image of a fractured bone. Initially, the unaltered X-ray encourages users to detect abnormalities on their own through unbiased observation. The subsequent stage introduces a red highlight, clearly marking the fracture site and confirming its location.

Sometimes the focus is not so much on a specific object, but rather on a pattern that appears in an image. This can be a little more demanding, since it can be an abstract-thinking process. In this case, you need to process what you see in a deeper way, using prior knowledge, too.

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Worked example 1

Let's look at the following easy example in **Figure 4** to make this point clear. What creatures have been walking on the beach, and what is the most probable direction of their motion?

Figure 4. Footprints of animals on a beach.

Credit: MelanieMaya, Getty Images

Pattern recognition tells you that one human and, most likely, two birds of the same species walked across this beach. Examining the orientation of the tracks, we can say that the human walked from bottom to top and the birds diagonally from the bottom to the left and right.

Quantitative analysis

You may often need to count or measure something that appears in an image. Let's see how we can classify the flowers in **Figure 5** and **6**. They look alike, because they belong to the same family. However, they are different.

Student view

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Figure 5. *Gentiana verna* — five petals.

Credit: Musat, Getty Images

Figure 6. *Gentianella ciliata* — four petals.

Credit: Martin Siepmann, Getty Images

If you carefully look at the images, you will notice that the flowers in **Figure 5** have five petals and in **Figure 6** they only have four petals. This is important data and will help a botanist to determine the species of plant.

As a slightly more advanced application of this task, let's try to measure the distance between two objects or points in an image. For this, you will need some information on the scale of the image. Let's look at the example in **Figure 7**. We would like to know the distance between the centre of the ball and the centre of the hole.

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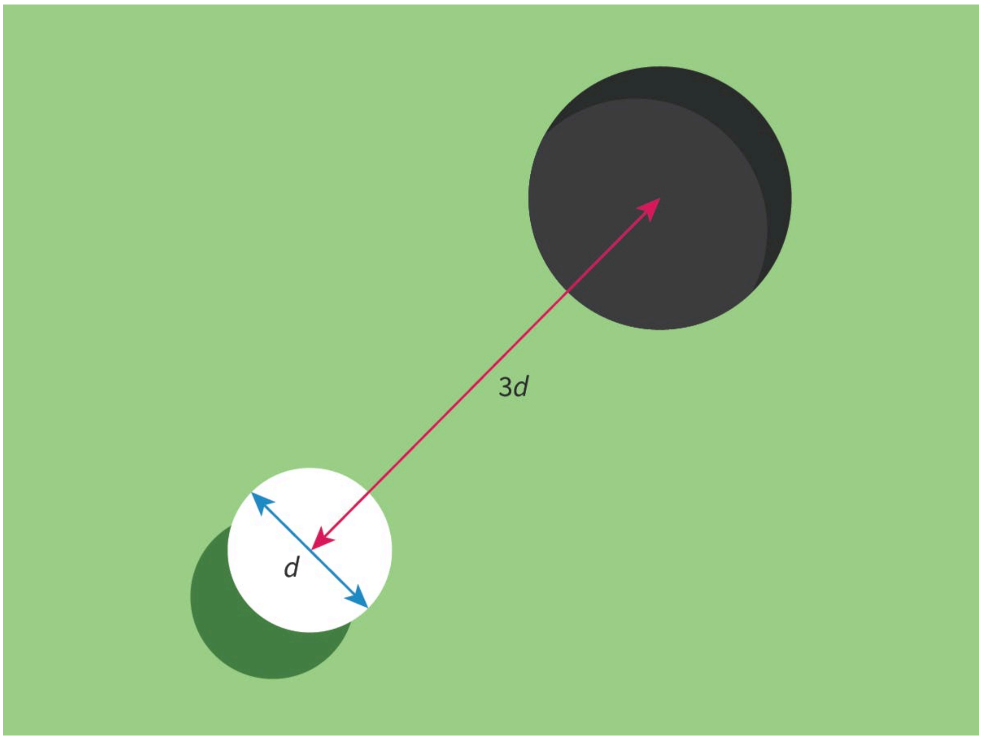

Figure 7. Knowing the diameter of a golf ball, you can measure the distance to the hole.

More information for figure 7

The image is an illustration showing a golf ball on the left and a hole on the right. The golf ball is depicted with a blue double-headed arrow labeled "d" indicating its diameter. A red arrow extends from the center of the golf ball to the center of the hole, labeled "3d," showing the measured distance using the ball's diameter as a unit. The background is green, representing a golf course. This diagram visually explains how to measure the distance between the center of a golf ball and a hole using the ball's diameter as a scaling unit.

[Generated by AI]

To estimate that, we use the diameter of the ball as a unit of measurement. Using your unaided eye it appears as though the centre of the ball to the centre of the hole distance is just over twice the diameter of the ball. If you use a ruler, you can approximate the distance to $2\frac{1}{3}$ ball diameters. If you know that the diameter of the golf ball is 4.3 cm, you can estimate its distance from the centre of the hole to be $4.3 \times 2.33 = 10.0$ cm.

In this section, we have introduced you to the basic ideas around image analysis. These tasks can be performed either by a human or with the help of algorithms. For more complex problems and especially in pattern recognition, AI applications are proving to be very helpful.

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Tool in action

To read more about the skills in this section and see examples of them being used in physics, take a look at the following:

- Section D.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/gravitational-field-gravitational-field-lines-and-gravitational-field-strength-id-46568/) Gravitational field, gravitational field lines and gravitational field strength.
- Section D.2.3a (/study/app/math-aa-hl/sid-423-cid-762593/book/electric-fields-id-46477/) Electric fields.
- Section E.1.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/atoms-and-photons-id-46593/) The nucleus and atomic energy levels.

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