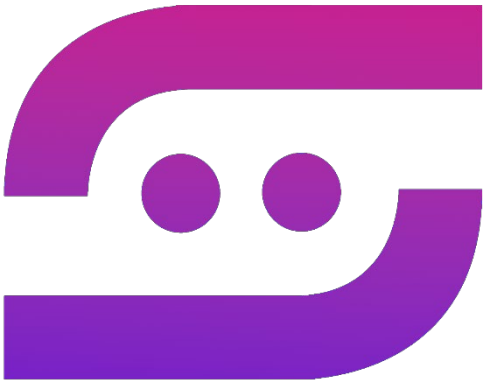
PROTEUS

LABS



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LABS LIST

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Contents

Introduction

Important links

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Corresponding International Baccalaureate Programme Topics

A. IB Middle Years Programme — Sciences (Years 1–5, ages 11–16)

The MYP Sciences framework organizes content around four **Key Concepts** (Change, Relationships, Systems, Communities), six discipline-specific **Related Concepts**, and six **Global Contexts**. Each lab below is mapped to its primary Key Concept, the two most relevant Related Concepts, and the Global Context the lab speaks to most clearly. Approximate MYP year is provided as a curriculum-planning hint.

MYP Biology

Lab No	Lab Name	MYP Year	Key Concept	Related Concepts	Global Context
4	Osmosis	3–5	Systems	Balance, Function	Scientific & technical innovation
21	Centrifugation	4–5	Change	Form, Function	Scientific & technical innovation
23	Blood and blood groups	4–5	Systems	Function, Form	Identities and relationships
24	Observation of animal cells	1–3	Systems	Form, Function	Scientific & technical innovation
25	Observation of plant cells	1–3	Systems	Form, Function	Scientific & technical innovation
26	Vegetal DNA	4–5	Relationships	Form, Function	Scientific & technical innovation
27	Germination	1–3	Change	Environment, Balance	Orientation in space and time
28	Analysis of stools	4–5	Systems	Function, Balance	Identities and relationships
29	Observation of saliva	3–5	Systems	Function, Energy	Identities and relationships
30	Chemistry of river water	3–5	Systems	Environment, Balance	Globalization and sustainability
31	Köhler illumination *(TBD 2026)*	3–5	Relationships	Form, Function	Scientific & technical innovation
32	Focusing microscope *(TBD 2026)*	3–5	Relationships	Form, Function	Scientific & technical innovation
33	Observation of river water *(TBD 2026)*	3–5	Systems	Environment, Balance	Globalization and sustainability

MYP Chemistry

Lab No	Lab Name	MYP Year	Key Concept	Related Concepts	Global Context
5	Identification of elements through bright flames	3–5	Change	Patterns, Models	Scientific & technical innovation
6	Gas identification	3–5	Change	Patterns, Transformation	Scientific & technical innovation
7	Separation of solid and liquid products	1–3	Change	Transformation, Function	Scientific & technical innovation
8	Separation of products by boiling point 1	3–4	Change	Transformation, Energy	Scientific & technical innovation
9	Separation of products by boiling point 2	4–5	Change	Transformation, Energy	Scientific & technical innovation
10	Melting point and density	1–3	Relationships	Patterns, Models	Scientific & technical innovation
11	Density	1–3	Relationships	Patterns, Movement	Scientific & technical innovation
12	Physical properties and identification of products	1–3	Change	Patterns, Function	Scientific & technical innovation
13	Nutrients	3–4	Systems	Function, Patterns	Identities and relationships
14	Heavy metal extraction	4–5	Change	Transformation, Function	Globalization and sustainability
15	Metal properties	1–3	Relationships	Patterns, Function	Scientific & technical innovation
16	The law of conservation of mass	1–3	Change	Models, Patterns	Scientific & technical innovation
38	Preparation of solution by dissolution	1–3	Change	Transformation, Models	Scientific & technical innovation
39	Changing the solubility of a solid	3–4	Change	Transformation, Energy	Scientific & technical innovation

40	Precipitation	3–4	Change	Transformation, Patterns	Scientific & technical innovation
41	Preparation of a solution	1–3	Change	Models, Function	Scientific & technical innovation
43	Dilutions	1–3	Relationships	Models, Patterns	Scientific & technical innovation
46	pH	1–3	Change	Patterns, Models	Scientific & technical innovation
47	Acid-base titration 1	3–5	Change	Transformation, Models	Scientific & technical innovation
48	pH of strong and weak acids	3–5	Change	Patterns, Models	Scientific & technical innovation
49	Using pH indicators	1–3	Change	Patterns, Models	Scientific & technical innovation
50	Conductivity and pH	3–5	Relationships	Patterns, Function	Scientific & technical innovation
51	Stoichiometry	3–5	Change	Models, Transformation	Scientific & technical innovation
52	Acid-base titration 2	4–5	Change	Transformation, Models	Scientific & technical innovation
53	The pressure of gases	3–4	Relationships	Patterns, Energy	Scientific & technical innovation
54	The relationship between volume and pressure of a gas 1	3–4	Relationships	Patterns, Models	Scientific & technical innovation
55	The relationship between volume and pressure of a gas 2	3–4	Relationships	Patterns, Models	Scientific & technical innovation
56	The relationship between a gas' temperature and its volume	3–4	Relationships	Patterns, Energy	Scientific & technical innovation

57	The relationship between gas solubility and temperature	3–5	Relationships	Patterns, Energy	Scientific & technical innovation
59	Reaction speed and enthalpy	4–5	Change	Transformation, Energy	Scientific & technical innovation
60	Reaction rate between molecules	3–5	Change	Models, Movement	Scientific & technical innovation
61	The influence of contact surface on reaction rate 1	3–4	Change	Patterns, Movement	Scientific & technical innovation
62	The influence of contact surface on reaction rate 2	3–4	Change	Patterns, Movement	Scientific & technical innovation
63	The influence of concentration on reaction rate 1	3–4	Change	Patterns, Movement	Scientific & technical innovation
64	The influence of concentration on reaction rate 2	3–4	Change	Patterns, Movement	Scientific & technical innovation
65	Hess's Law	4–5	Change	Energy, Models	Scientific & technical innovation
66	Endothermic & exothermic reactions	3–5	Change	Energy, Transformation	Scientific & technical innovation
67	Specific heat capacity	3–5	Relationships	Energy, Patterns	Scientific & technical innovation
70	The qualitative aspect of chemical equilibrium	4–5	Systems	Patterns, Balance	Scientific & technical innovation
71	Le Chatelier's principle	4–5	Systems	Patterns, Balance	Scientific & technical innovation
72	Water electrolysis	4–5	Change	Transformation, Energy	Scientific & technical innovation
73	Conductivity	3–5	Relationships	Patterns, Function	Scientific & technical innovation

MYP Physics

Lab No	Lab Name	MYP Year	Key Concept	Related Concepts	Global Context
74	Reading a resistor	3–4	Systems	Models, Function	Scientific & technical innovation
75	Electrical circuit assembly	3–4	Systems	Models, Function	Scientific & technical innovation
76	Assembling an electrical circuit in parallel	3–4	Systems	Models, Function	Scientific & technical innovation
77	Impact of current on the brightness of a lamp	3–4	Relationships	Energy, Function	Scientific & technical innovation
78	Static electricity	3–4	Change	Force, Models	Scientific & technical innovation
79	Magnetic fields	3–5	Relationships	Force, Models	Scientific & technical innovation
80	Solenoids	4–5	Relationships	Force, Function	Scientific & technical innovation
81	Energy efficiency	3–5	Systems	Energy, Consequences	Globalization and sustainability
110	Kirchhoff law	4–5	Systems	Models, Patterns	Scientific & technical innovation
82	Effective force	3–5	Relationships	Force, Movement	Scientific & technical innovation
83	The mechanical energy of a moving object	3–5	Change	Energy, Movement	Scientific & technical innovation
84	Constant acceleration	3–5	Change	Movement, Patterns	Scientific & technical innovation
85	The relationship between the deformation of a spring and the restoring force	3–5	Relationships	Force, Patterns	Scientific & technical innovation

86	The operation of a hoist	3–5	Systems	Force, Movement	Scientific & technical innovation
87	Mechanical advantage in theater stage design	3–5	Systems	Force, Function	Personal & cultural expression
88	The relationship between the resultant force and acceleration	3–5	Relationships	Force, Movement	Scientific & technical innovation
91	Kinetic energy	3–5	Change	Energy, Movement	Scientific & technical innovation
92	Reverse bungee *(TBD 2026)*	3–5	Change	Energy, Force	Scientific & technical innovation
106	Rolling motion on inclined ramps	3–5	Change	Movement, Energy	Scientific & technical innovation

B. IB Diploma Programme — Sciences (ages 16–18)

IB DP Biology

Topic	Programme	Syllabus Reference	Lab No	Lab Name
Cells	DP Biology	Cell structure	24	Observation of animal cells
Cells	DP Biology	Cell structure	25	Observation of plant cells
Cells and diffusion	DP Biology	Membrane transport, cell structure	4	Osmosis
Cycles and reproduction	DP Biology	Reproduction, adaptation	27	Germination
Cycles, Ecosystems	DP Biology	Transfer of energy and matter	33	Observation of river water
Enzymes	DP Biology	Enzyme activity	29	Observation of saliva
Genetics	DP Biology	DNA replication, inheritance	26	Vegetal DNA
Human systems	DP Biology	Integration of body systems	23	Blood and blood groups
Human systems	DP Biology	Integration of body systems	21	Centrifugation
Organisms	DP Biology	Metabolism and digestion	28	Analysis of stools
Organisms, metabolism	DP Biology	Macronutrients, enzymes	13	Nutrients

Sustainability	DP Biology	Ecosystems, sustainability	30	Chemistry of river water

IB Codes Legend

MYP Key Concepts organize content at the broadest level: Change, Relationships, Systems, Communities.

MYP Related Concepts (Sciences):

- Biology: Balance, Consequences, Energy, Environment, Evidence, Form, Function, Interaction, Models, Movement, Patterns, Transformation
- Chemistry: Balance, Conditions, Consequences, Energy, Evidence, Form, Function, Interaction, Models, Movement, Patterns, Transformation
- Physics: Consequences, Development, Energy, Environment, Evidence, Form, Function, Interaction, Models, Movement, Patterns, Transformation

MYP Global Contexts: Identities and relationships; Orientation in space and time; Personal and cultural expression; Scientific and technical innovation; Globalization and sustainability; Fairness and development.

DP codes map to the current (2023) IB curriculum themes: **Structure** (1.1–1.5, 2.1–2.4, 3.1–3.2) and **Reactivity** (1.1–1.4, 2.1–2.3, 3.1–3.4) for Chemistry; **A** (Forces, energy, momentum), **B** (Particulate matter), **C** (Wave behaviour), **D** (Fields), **E** (Nuclear and quantum) for Physics; the four major DP Biology themes (Unity and diversity, Form and function, Interaction and interdependence, Continuity and change) for Biology.

Next Generation Science Standards (NGSS) Disciplinary Core Ideas (DCI) Arrangements Mapping

This section deepens the existing DCI-level mapping in three ways:

1. **Performance Expectations (PEs)** are named explicitly. PE codes follow the format *[HS|MS]-[subject]-[number]*, e.g., HS-PS1-2 means "High School Physical Science 1, Performance Expectation 2."
2. **Science and Engineering Practices (SEPs)** are tagged per lab. NGSS defines 8 SEPs; the most directly engaged are listed.
3. **Crosscutting Concepts (CCCs)** are tagged per lab. NGSS defines 7 CCCs.

Where a lab is appropriate for both middle school and high school audiences, both MS- and HS- PEs are listed.

A. NGSS Mapping (in order of Proteus Labs)

Tutorials and Introductory Skills

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
1	Balance Tutorial	HS-ETS1-1	MS-PS1-7	SEP 3 (Planning investigations); SEP 5 (Mathematics)	CCC 3 (Scale, proportion, quantity)
2	Introduction Tutorial	HS-ETS1-1; HS-PS1-3	MS-PS1-3	SEP 3 (Planning investigations)	CCC 1 (Patterns); CCC 6 (Structure and function)
3	Volume Tutorial	HS-PS1-3	MS-PS1-1	SEP 3 (Planning investigations); SEP 5 (Mathematics)	CCC 3 (Scale, proportion, quantity)
34	Introduction to laboratory safety	HS-ETS1-1	—	SEP 1 (Asking questions and defining problems); SEP 8 (Communicating information)	CCC 6 (Structure and function)
42	Introduction to laboratory instruments	HS-ETS1-1	—	SEP 3 (Planning investigations); SEP 8 (Communicating information)	CCC 6 (Structure and function)

Chemical and Physical Properties

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
4	Osmosis	HS-LS1-2; HS-LS1-3	MS-LS1-3	SEP 2 (Developing models); SEP 4 (Analyzing data)	CCC 4 (Systems and system models); CCC 7 (Stability and change)

5	Identification of elements through bright flames	HS-PS1-1; HS-PS4-3	MS-PS1-1	SEP 4 (Analyzing data); SEP 8 (Communicating information)	CCC 1 (Patterns)
6	Gas identification	HS-PS1-3	MS-PS1-2	SEP 4 (Analyzing data); SEP 6 (Constructing explanations)	CCC 1 (Patterns); CCC 6 (Structure and function)
7	Separation of solid and liquid products	HS-PS1-3	MS-PS1-2	SEP 3 (Planning investigations)	CCC 6 (Structure and function)
8	Separation of products by boiling point 1	HS-PS1-3	MS-PS1-4	SEP 3 (Planning investigations); SEP 5 (Mathematics)	CCC 5 (Energy and matter); CCC 7 (Stability and change)
9	Separation of products by boiling point 2	HS-PS1-3	MS-PS1-4	SEP 3 (Planning investigations); SEP 5 (Mathematics)	CCC 5 (Energy and matter)
10	Melting point and density	HS-PS1-3	MS-PS1-1	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 1 (Patterns); CCC 6 (Structure and function)
11	Density	HS-PS1-3	MS-PS1-1	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 3 (Scale, proportion, quantity)
12	Physical properties and identification of products	HS-PS1-3	MS-PS1-1; MS-PS1-2	SEP 4 (Analyzing data); SEP 6 (Constructing explanations)	CCC 1 (Patterns); CCC 6 (Structure and function)
13	Nutrients	HS-LS1-6	MS-LS1-7	SEP 4 (Analyzing data); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter); CCC 6 (Structure and function)
14	Heavy metal extraction	HS-PS1-2; HS-ESS3-4	MS-PS1-2	SEP 3 (Planning investigations); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)
15	Metal properties	HS-PS1-1; HS-PS1-2	MS-PS1-2	SEP 4 (Analyzing data); SEP 6 (Constructing explanations)	CCC 1 (Patterns); CCC 6 (Structure and function)
16	The law of conservation of mass	HS-PS1-7	MS-PS1-5	SEP 5 (Mathematics); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)

Biology

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
21	Centrifugation	HS-LS1-2	MS-LS1-2	SEP 3 (Planning investigations)	CCC 6 (Structure and function)

23	Blood and blood groups	HS-LS1-2	MS-LS1-3	SEP 4 (Analyzing data); SEP 6 (Constructing explanations)	CCC 4 (Systems and system models); CCC 6 (Structure and function)
24	Observation of animal cells	HS-LS1-2	MS-LS1-1; MS-LS1-2	SEP 2 (Developing models); SEP 6 (Constructing explanations)	CCC 4 (Systems and system models); CCC 6 (Structure and function)
25	Observation of plant cells	HS-LS1-2	MS-LS1-1; MS-LS1-2	SEP 2 (Developing models); SEP 6 (Constructing explanations)	CCC 4 (Systems and system models); CCC 6 (Structure and function)
26	Vegetal DNA	HS-LS3-1	MS-LS3-1	SEP 1 (Asking questions); SEP 3 (Planning investigations)	CCC 6 (Structure and function)
27	Germination	HS-LS1-5	MS-LS1-5	SEP 3 (Planning investigations); SEP 4 (Analyzing data)	CCC 5 (Energy and matter); CCC 7 (Stability and change)
28	Analysis of stools	HS-LS1-7	MS-LS1-7	SEP 6 (Constructing explanations); SEP 8 (Communicating information)	CCC 5 (Energy and matter)
29	Observation of saliva	HS-LS1-6	MS-LS1-7	SEP 3 (Planning investigations); SEP 4 (Analyzing data)	CCC 5 (Energy and matter); CCC 6 (Structure and function)
30	Chemistry of river water	HS-LS2-7; HS-ESS3-3; HS-ESS3-4	MS-LS2-1; MS-ESS3-3	SEP 4 (Analyzing data); SEP 7 (Engaging in argument from evidence)	CCC 2 (Cause and effect); CCC 4 (Systems and system models)
31	Köhler illumination *(TBD 2026)*	HS-PS4-3	MS-PS4-2	SEP 3 (Planning investigations)	CCC 6 (Structure and function)
32	Focusing microscope *(TBD 2026)*	HS-PS4-3	MS-PS4-2	SEP 3 (Planning investigations)	CCC 6 (Structure and function)
33	Observation of river water *(TBD 2026)*	HS-LS2-7; HS-PS4-3	MS-LS2-1	SEP 4 (Analyzing data); SEP 7 (Engaging in argument from evidence)	CCC 4 (Systems and system models)

Solutions

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
38	Preparation of solution by dissolution	HS-PS1-3	MS-PS1-4	SEP 3 (Planning investigations); SEP 5 (Mathematics)	CCC 5 (Energy and matter)
39	Changing the solubility of a solid	HS-PS1-5	MS-PS1-4	SEP 4 (Analyzing data)	CCC 2 (Cause and effect); CCC 5 (Energy and matter)
40	Precipitation	HS-PS1-2	MS-PS1-2	SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)
41	Preparation of a solution	HS-PS1-7	MS-PS1-1	SEP 5 (Mathematics)	CCC 3 (Scale, proportion, quantity)
43	Dilutions	HS-PS1-7	MS-PS1-1	SEP 5 (Mathematics)	CCC 3 (Scale, proportion, quantity)

Acids and Bases

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
46	pH	HS-PS1-2	MS-PS1-2	SEP 3 (Planning investigations); SEP 4 (Analyzing data)	CCC 1 (Patterns)
47	Acid-base titration 1	HS-PS1-2; HS-PS1-7	MS-PS1-2	SEP 3 (Planning investigations); SEP 5 (Mathematics)	CCC 3 (Scale, proportion, quantity)
48	pH of strong and weak acids	HS-PS1-5	MS-PS1-2	SEP 4 (Analyzing data); SEP 6 (Constructing explanations)	CCC 1 (Patterns)
49	Using pH indicators	HS-PS1-2	MS-PS1-2	SEP 4 (Analyzing data)	CCC 1 (Patterns)
50	Conductivity and pH	HS-PS1-2	MS-PS1-2	SEP 4 (Analyzing data)	CCC 2 (Cause and effect)
51	Stoichiometry	HS-PS1-7	MS-PS1-5	SEP 5 (Mathematics); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)
52	Acid-base titration 2	HS-PS1-2; HS-PS1-7	MS-PS1-2	SEP 3 (Planning investigations); SEP 5 (Mathematics)	CCC 5 (Energy and matter)

Gases

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs

53	The pressure of gases	HS-PS1-3; HS-PS3-2	MS-PS1-4	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 5 (Energy and matter)
54	The relationship between volume and pressure of a gas 1	HS-PS3-2	MS-PS1-4	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 1 (Patterns); CCC 5 (Energy and matter)
55	The relationship between volume and pressure of a gas 2	HS-PS3-2	MS-PS1-4	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 1 (Patterns); CCC 5 (Energy and matter)
56	The relationship between a gas' temperature and its volume	HS-PS3-2	MS-PS1-4	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 1 (Patterns); CCC 5 (Energy and matter)
57	The relationship between gas solubility and temperature	HS-PS1-5; HS-PS3-2	MS-PS1-4	SEP 4 (Analyzing data)	CCC 1 (Patterns); CCC 5 (Energy and matter)

Kinetics and Thermodynamics

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
59	Reaction rate and enthalpy	HS-PS1-4; HS-PS1-5	MS-PS1-6	SEP 3 (Planning investigations); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter); CCC 7 (Stability and change)
60	Reaction rate between molecules	HS-PS1-5	MS-PS1-2	SEP 2 (Developing models); SEP 4 (Analyzing data)	CCC 2 (Cause and effect)
61	The influence of contact surface on reaction rate 1	HS-PS1-5	MS-PS1-2	SEP 3 (Planning investigations); SEP 4 (Analyzing data)	CCC 2 (Cause and effect)
62	The influence of contact surface on reaction rate 2	HS-PS1-5	MS-PS1-2	SEP 3 (Planning investigations); SEP 4 (Analyzing data)	CCC 2 (Cause and effect)
63	The influence of concentration on reaction rate 1	HS-PS1-5	MS-PS1-2	SEP 3 (Planning investigations); SEP 4 (Analyzing data)	CCC 2 (Cause and effect)
64	The influence of concentration on reaction rate 2	HS-PS1-5	MS-PS1-2	SEP 3 (Planning investigations); SEP 4 (Analyzing data)	CCC 2 (Cause and effect)
65	Hess's Law	HS-PS1-4	MS-PS1-6	SEP 5 (Mathematics); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)
66	Endothermic & exothermic reactions	HS-PS1-4	MS-PS1-6	SEP 3 (Planning investigations); SEP 6	CCC 5 (Energy and matter)

				(Constructing explanations)	
67	Specific heat capacity	HS-PS3-4	MS-PS3-3; MS-PS3-4	SEP 5 (Mathematics)	CCC 5 (Energy and matter); CCC 7 (Stability and change)

Chemical Equilibrium

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
70	The qualitative aspect of chemical equilibrium	HS-PS1-6	—	SEP 2 (Developing models); SEP 6 (Constructing explanations)	CCC 7 (Stability and change)
71	Le Chatelier's principle	HS-PS1-6	—	SEP 3 (Planning investigations); SEP 7 (Engaging in argument from evidence)	CCC 2 (Cause and effect); CCC 7 (Stability and change)

Electrochemistry

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
72	Water electrolysis	HS-PS1-2; HS-PS3-1	MS-PS1-2	SEP 3 (Planning investigations); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)
73	Conductivity	HS-PS1-2; HS-PS3-3	MS-PS1-2	SEP 4 (Analyzing data)	CCC 2 (Cause and effect)

Electricity

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
74	Reading a resistor	HS-PS3-3	MS-PS3-3	SEP 8 (Communicating information)	CCC 6 (Structure and function)
75	Electrical circuit assembly	HS-PS3-3	MS-PS3-3	SEP 2 (Developing models); SEP 3 (Planning investigations)	CCC 4 (Systems and system models)
76	Assembling an electrical circuit in parallel	HS-PS3-3	MS-PS3-3	SEP 2 (Developing models); SEP 3 (Planning investigations)	CCC 4 (Systems and system models)
77	Impact of current on the brightness of a lamp	HS-PS3-3	MS-PS3-3	SEP 4 (Analyzing data)	CCC 2 (Cause and effect); CCC 5 (Energy and matter)
78	Static electricity	HS-PS2-4	MS-PS2-3	SEP 2 (Developing models); SEP 3 (Planning investigations)	CCC 2 (Cause and effect)

79	Magnetic fields	HS-PS2-5	MS-PS2-3; MS-PS2-5	SEP 2 (Developing models); SEP 3 (Planning investigations)	CCC 2 (Cause and effect); CCC 6 (Structure and function)
80	Solenoids	HS-PS2-5; HS-PS3-5	MS-PS2-3	SEP 2 (Developing models); SEP 3 (Planning investigations)	CCC 4 (Systems and system models); CCC 6 (Structure and function)
81	Energy efficiency	HS-PS3-3	MS-PS3-3	SEP 4 (Analyzing data); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)
110	Kirchhoff law	HS-PS3-3	MS-PS3-3	SEP 5 (Mathematics); SEP 6 (Constructing explanations)	CCC 4 (Systems and system models); CCC 5 (Energy and matter)

Physics (Mechanics)

Lab	Lab Name	Primary PE(s)	Secondary PE(s)	SEPs	CCCs
82	Effective force	HS-PS2-1	MS-PS2-2	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 2 (Cause and effect)
83	The mechanical energy of a moving object	HS-PS3-1; HS-PS3-2	MS-PS3-1; MS-PS3-5	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 5 (Energy and matter)
84	Constant acceleration	HS-PS2-1	MS-PS2-2	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 1 (Patterns)
85	The relationship between the deformation of a spring and the restoring force	HS-PS2-1	MS-PS2-2	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 1 (Patterns); CCC 2 (Cause and effect)
86	The operation of a hoist	HS-PS3-3	MS-PS3-5	SEP 2 (Developing models); SEP 6 (Constructing explanations)	CCC 4 (Systems and system models); CCC 5 (Energy and matter)
87	Mechanical advantage in theater stage design	HS-PS3-3; HS-ETS1-2	MS-PS3-5	SEP 2 (Developing models); SEP 6 (Constructing explanations)	CCC 4 (Systems and system models); CCC 6 (Structure and function)
88	The relationship between the resultant force and acceleration	HS-PS2-1	MS-PS2-2	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 2 (Cause and effect)

91	Kinetic energy	HS-PS3-1; HS-PS3-2	MS-PS3-1	SEP 5 (Mathematics); SEP 6 (Constructing explanations)	CCC 5 (Energy and matter)
92	Reverse bungee *(TBD 2026)*	HS-PS2-1; HS-PS3-2	MS-PS3-5	SEP 2 (Developing models); SEP 4 (Analyzing data)	CCC 5 (Energy and matter)
106	Rolling motion on inclined ramps	HS-PS2-1; HS-PS3-2	MS-PS2-2	SEP 4 (Analyzing data); SEP 5 (Mathematics)	CCC 5 (Energy and matter)

B. NGSS Mapping (in order of NGSS Performance Expectation)

The same lab-to-PE links above, organized by PE code, give a teacher who's lesson-planning around a specific NGSS standard a one-stop list of relevant Proteus labs.

Middle School — Physical Sciences

PE Code	Performance Expectation (paraphrased)	Proteus Labs
MS-PS1-1	Develop models of atoms and molecules	3, 10, 11, 12, 41, 43
MS-PS1-2	Analyze and interpret data on chemical properties	6, 7, 12, 14, 15, 40, 46, 47, 48, 49, 50, 52, 60–64, 72, 73
MS-PS1-3	Synthetic materials from natural resources	2
MS-PS1-4	Develop models predicting state changes	8, 9, 38, 39, 53, 54, 55, 56, 57
MS-PS1-5	Conservation of mass in reactions	16, 51
MS-PS1-6	Design devices using endo/exothermic reactions	59, 65, 66
MS-PS1-7	Engineering: measurement and tools	1
MS-PS2-2	Forces and motion	82, 84, 85, 88, 106
MS-PS2-3	Electric and magnetic forces	78, 79, 80
MS-PS2-5	Fields between objects	79
MS-PS3-1	Kinetic energy and mass/speed	83, 91
MS-PS3-3	Thermal energy transfer	67, 74, 75, 76, 77, 81, 110

MS-PS3-4	Plan investigations on temperature/mass changes	67
MS-PS3-5	Energy transfer in collisions	83, 86, 87, 92
MS-PS4-2	Reflection, absorption, transmission of waves	31, 32

Middle School — Life Sciences

PE Code	Performance Expectation (paraphrased)	Proteus Labs
MS-LS1-1	Cells as basic unit of life	24, 25
MS-LS1-2	Develop models of cell parts	21, 24, 25
MS-LS1-3	Organism body systems	4, 23
MS-LS1-5	Environmental and genetic factors on growth	27
MS-LS1-7	Food rearranged through chemical reactions	13, 28, 29
MS-LS2-1	Resource availability and organism populations	30, 33
MS-LS3-1	DNA as the source of genetic information	26

Middle School — Earth and Space Sciences

PE Code	Performance Expectation (paraphrased)	Proteus Labs
MS-ESS3-3	Method to monitor human impact on environment	30

High School — Physical Sciences

PE Code	Performance Expectation (paraphrased)	Proteus Labs
HS-PS1-1	Periodic table predicts properties	5, 15
HS-PS1-2	Outcomes of simple chemical reactions	14, 15, 40, 46, 47, 49, 50, 52, 72, 73
HS-PS1-3	Investigate substance properties	2, 3, 6, 7, 8, 9, 10, 11, 12, 38, 53
HS-PS1-4	Energy changes in chemical bonds	59, 65, 66
HS-PS1-5	Concentration and rate of reaction	39, 48, 57, 59, 60–64
HS-PS1-6	Equilibrium and Le Chatelier	70, 71
HS-PS1-7	Mass conservation in reactions	16, 41, 43, 47, 51, 52
HS-PS2-1	Newton’s second law, F=ma	82, 84, 85, 88, 92, 106
HS-PS2-4	Coulomb’s law and charges	78
HS-PS2-5	Electric current produces magnetic field	79, 80
HS-PS3-1	Energy transfer model	72, 83, 91
HS-PS3-2	Energy at macroscopic vs molecular scale	53, 54, 55, 56, 57, 83, 91, 92, 106
HS-PS3-3	Energy conversion devices	73, 74, 75, 76, 77, 81, 86, 87, 110
HS-PS3-4	Calorimetry / thermal equilibrium	67
HS-PS3-5	Forces between objects at distance	80
HS-PS4-3	Wave / particle nature of EM radiation	5, 31, 32, 33

High School — Life Sciences

PE Code	Performance Expectation (paraphrased)	Proteus Labs
HS-LS1-2	Hierarchical organization of body systems	4, 21, 23, 24, 25
HS-LS1-3	Feedback maintains homeostasis	4
HS-LS1-5	Photosynthesis	27
HS-LS1-6	Carbon-based molecules in living systems	13, 29
HS-LS1-7	Cellular respiration	28
HS-LS2-7	Reduce impact of human activities on biodiversity	30, 33
HS-LS3-1	DNA and inheritance	26

High School — Earth and Space / Engineering

PE Code	Performance Expectation (paraphrased)	Proteus Labs
HS-ESS3-3	Sustainability and biodiversity	30
HS-ESS3-4	Reduce impact of human activities	14, 30
HS-ETS1-1	Engineering design — define problems	1, 2, 34, 42
HS-ETS1-2	Break problems into smaller solvable problems	87

NGSS Codes Legend

Performance Expectation (PE) format: *[HS|MS]-[discipline][topic]-[number]*

- HS = high school grades 9–12; MS = middle school grades 6–8
- Disciplines: **PS** = Physical Sciences; **LS** = Life Sciences; **ESS** = Earth and Space Sciences; **ETS** = Engineering, Technology, and Applications of Science
- Topic number identifies the DCI within that discipline (PS1 = Matter and Its Interactions; PS2 = Motion and Stability; PS3 = Energy; PS4 = Waves; LS1 = From Molecules to Organisms; LS2 = Ecosystems; LS3 = Heredity; LS4 = Biological Evolution; ESS1 = Earth's Place in the Universe; ESS2 = Earth's Systems; ESS3 = Earth and Human Activity; ETS1 = Engineering Design)
- The final number identifies the specific PE within the topic

Science and Engineering Practices (8 SEPs):

1. Asking questions (science) and defining problems (engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (science) and designing solutions (engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Crosscutting Concepts (7 CCCs):

1. Patterns
2. Cause and effect: mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: flows, cycles, and conservation
6. Structure and function
7. Stability and change

001 — Balance Tutorial

IB Programme	Chemistry — Measurement skills
Secondary Programme	DP Chemistry
NGSS (HS)	HS-ETS1-1 · SEP 3, SEP 5 · CCC 3
NGSS (MS)	MS-PS1-7
Summary	Mass measurement and precision

OVERVIEW

The triple beam balance is one of the oldest instruments still in everyday laboratory use, and one of the most reliable: it compares the unknown mass on its pan against sliding standard masses on three graduated beams, using nothing but the lever principle. Because it compares masses rather than measuring a force, its reading does not depend on the strength of gravity and it needs no batteries and no calibration curve — only a clean pan and a properly zeroed pointer. Weighing is the single most common operation in experimental science, and nearly every quantitative laboratory in this catalogue begins with it. In this tutorial, you will learn the complete weighing routine on a triple beam balance: zeroing and calibrating the instrument, weighing a solid in whole pieces (magnesium ribbons) and a solid in powder form (magnesium oxide), and obtaining the mass of each substance by subtraction — weighing the empty boat first, so that the container's mass drops out of the result.

OBJECTIVES

- Operation of the triple beam balance
- Weighing technique
- Understanding precision
- Laboratory habits

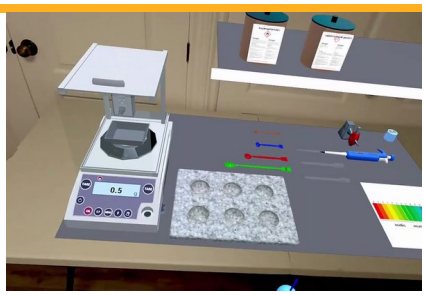
WHAT STUDENTS DO

- Calibrate the balance — return all riders to zero, clean the pan and turn the adjustment screw until the pointer rests on zero.
- Read beam by beam — advance each rider until the pointer drops below zero, step back one notch, then sum the three beam readings.
- Weigh solid and powder — weigh the empty boat, then the five magnesium ribbons (2.75 g) and 5 mL of magnesium oxide powder (17.9 g), subtracting the boat each time.

Lab page: proteus-vr.com/labslist/balance-tutorial/

002 — Introduction Tutorial

IB Programme	Chemistry — Foundational skills / Nature of Science
Secondary Programme	DP Chemistry
NGSS (HS)	HS-ETS1-1; HS-PS1-3 · SEP 3 · CCC 1, CCC 6
NGSS (MS)	MS-PS1-3
Summary	Virtual lab orientation and personal protective equipment



OVERVIEW

Every laboratory in this catalogue is worked inside the same virtual environment, and this tutorial is where its habits are learned. Immersive simulation is now a standard training tool in science education for the same reason flight simulators are standard in aviation: the student practises real procedures — donning protective equipment, weighing, measuring volumes, testing pH — with none of the risks of real chemicals and with the freedom to restart at any moment. The techniques themselves are the real ones: an electronic balance is tared before use, a volume is read at the bottom of the meniscus, a solution's pH is judged by comparing an indicator's colour against a chart. In this tutorial, you will learn to move and interact in the virtual laboratory with hand tracking or controllers, put on the personal protective equipment, and then take on four short challenges: weigh a powdered solid on the electronic scale, measure a volume of liquid with a graduated cylinder, prepare a solution from a solid sample and check its pH with an indicator, and finally review and send your results from the tablet.

OBJECTIVES

- Familiarization with the virtual environment
- Use of protective equipment
- Measurement of substances
- Basic chemical experimentation
- Analysis and communication of results

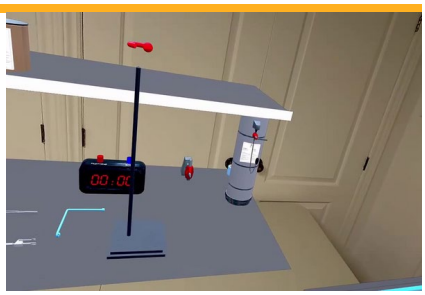
WHAT STUDENTS DO

- Gear up and tare — don full PPE, place the weighing boat on the electronic balance and press tare to zero it.
- Weigh and measure — spoon 5 mL of magnesium powder (8.7 g) into the boat, then draw 50 mL of cold water into the cylinder.
- Test the pH — dissolve 0.12 mL of NaOH powder in 5 mL of water and add indicator on the well plate; pH is about 14.

Lab page: proteus-vr.com/labslist/introduction-tutorial/

003 — Volume Tutorial

IB Programme	Chemistry — Measurement of matter
Secondary Programme	DP Chemistry / DP Physics
NGSS (HS)	HS-PS1-3 · SEP 3, SEP 5 · CCC 3
NGSS (MS)	MS-PS1-1
Summary	Volume measurement across states



OVERVIEW

Volume is measured differently for each state of matter, and this tutorial teaches all three techniques in one session. A liquid can be poured into a graduated cylinder and read directly — provided the reading is taken at the base of the meniscus, the curve the liquid's surface tension forms against the glass. A solid, especially an irregular one that no ruler can capture, is measured by displacement: immersed in a brim-full overflow vessel, it pushes out exactly its own volume of water, which is caught and read in a cylinder. A gas is measured by letting it displace water from an inverted, water-filled burette — the gas bubbles up, the water level falls, and the graduations record how much space the gas has claimed. In this tutorial, you will measure 70 mL of water in a graduated cylinder, determine the volume of five pieces of lead with the overflow vessel, and collect a gas over water in a burette while a stopwatch and the tablet's Volume-versus-Time graph record the flow.

OBJECTIVES

- Measurement technique for each state of matter
- Application of physical principles
- Instrument handling
- Reading and recording

WHAT STUDENTS DO

- Measure a liquid — pour 70 mL of tap water into the graduated cylinder and confirm the volume at the base of the meniscus.
- Displace water with a solid — fill the 500 mL overflow vessel, add five lead pieces (170.2 g) with tweezers and collect 15 mL of overflow.
- Collect a gas — invert the water-filled burette in a 1 L beaker holding at least 800 mL of water, then let air fill it halfway.

Lab page: proteus-vr.com/labslist/volume-tutorial/

034 — Introduction to laboratory safety

IB Programme	Chemistry — Laboratory safety & ethics
Secondary Programme	DP Chemistry
NGSS (HS)	HS-ETS1-1 · SEP 1, SEP 8 · CCC 6
NGSS (MS)	—
Summary	Laboratory safety and risk awareness

OVERVIEW

Laboratory safety is the set of practices that makes experimental work possible at all. In a research, industrial or teaching laboratory, every procedure is preceded by an assessment of what could go wrong, and by the choice of equipment and behaviour that keeps a foreseeable incident from becoming an injury. A school laboratory contains open flames, hot surfaces, mains-powered instruments, corrosive and flammable substances and fragile glassware, and each of those hazards is managed by a specific combination of three things: protective equipment worn on the body, a procedure followed in a fixed order, and an emergency device whose location is known before it is needed. Two of those hazards are made explicit here, and they behave very differently. A Bunsen burner flame releases the chemical energy of a hydrocarbon at a temperature near 1500 °C and announces itself: it is luminous, it is noisy and it is unambiguous. A hot plate at 100 °C is fully capable of causing a burn and announces nothing at all, because a surface does not begin to glow in the visible range until roughly 500 °C. The energy still leaves the plate — as a rising column of hot air and as infrared radiation whose peak wavelength lies far outside the range the eye can detect — so the hazard has to be inferred from the instrument's own readout and from the procedure rather than seen.

OBJECTIVES

- Selection and use of personal protective equipment
- Location and purpose of emergency equipment
- Safe handling of heat sources
- Recognition of a hazard that gives no visual signal
- Laboratory rules and personal conduct
- Transfer to other laboratory settings

WHAT STUDENTS DO

- Suit up — put on the lab coat, safety goggles and nitrile gloves before touching any equipment.
- Point out safety stations — use the laser pointer to identify each emergency device positioned around the laboratory.
- Test the heat sources — swap to thermal gloves, pass a hand above the lit burner and the hot plate at 100 °C, then cool it to 15 °C.

Lab page: proteus-vr.com/labslist/034-laboratory-safety/

042 — Introduction to laboratory instruments

IB Programme	Chemistry — Experimental techniques
Secondary Programme	DP Chemistry
NGSS (HS)	HS-ETS1-1 · SEP 3, SEP 8 · CCC 6
NGSS (MS)	—
Summary	Identification and use of equipment

OVERVIEW

Every experimental result begins with a choice of instrument. A laboratory bench holds glassware that looks interchangeable but is not: a beaker and a volumetric flask may both hold 100 mL, yet one carries graduations for convenience while the other is calibrated to a single volume within a tenth of a millilitre. Knowing which is which, and handling each correctly, is the difference between a measurement and a guess. In a working laboratory it is also the difference between a routine session and a broken burette, a spilled reagent or a chemical burn, which is why professional practice puts equipment familiarity before any procedure. The principle underneath the distinction is simple and quantitative: every instrument has a tolerance, and the tolerance of the least precise instrument used in a procedure sets the precision of the final result. Instruments also sort naturally by purpose rather than by appearance — some measure a quantity, some only contain a liquid, some transfer it, some hold other equipment steady, and some sense a physical property electronically. Learning them by function is far more useful than memorising a list of names, because it is function that decides which instrument a given experiment requires.

OBJECTIVES

- Recognition of the standard bench inventory
- Classification by function
- Understanding precision and tolerance
- Correct handling of fragile and precise equipment
- Safe handling of a corrosive reagent
- Organisation of the working space

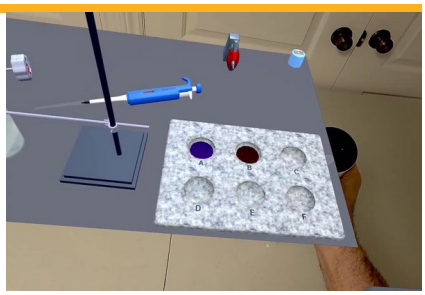
WHAT STUDENTS DO

- Pick up the glassware — locate and handle the wash bottle, graduated cylinder, beaker, Erlenmeyer flask, volumetric flask and test tube.
- Take up measuring tools — handle the dropper, pipette, burette, funnel, spatula, weighing boat, tongs, thermometer, pH meter and stopwatch.
- Assemble supporting apparatus — fit the universal clamp, drop the stir bar into the beaker, and place the lid on the calorimeter.

Lab page: proteus-vr.com/labslist/042-instruments-introduction/

004 — Osmosis

IB Programme	Biology — Cells and diffusion
Secondary Programme	DP Biology
Syllabus Reference	Membrane transport, cell structure
NGSS (HS)	HS-LS1-2; HS-LS1-3 · SEP 2, SEP 4 · CCC 4, CCC 7
NGSS (MS)	MS-LS1-3
Summary	Diffusion and osmosis demonstration



OVERVIEW

Every living cell is enclosed by a membrane that lets some substances through and holds others back. That selectivity is what allows a cell to keep its proteins and sugars while still exchanging water, salts and nutrients with its surroundings. The same principle is used industrially in water purification and, most familiarly, in kidney dialysis, where a machine performs the filtration a failing kidney no longer can. A membrane of this kind is described as selectively permeable : it is perforated by pores of a particular size, and whether a dissolved substance can cross depends chiefly on how large its molecules are. Small molecules and ions pass through readily and spread out by diffusion, moving from where they are concentrated to where they are dilute until they are evenly distributed. Large molecules are simply too big to fit and stay where they are. Water itself crosses freely in both directions, and its net movement toward the more concentrated side is what is properly called osmosis. In this laboratory you will fill a dialysis bag with a mixture of three substances of very different molecular size — starch, sodium chloride and glucose — and suspend it in a beaker of distilled water.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment
- Assembling and handling a dialysis membrane
- Accurate transfer of small volumes
- Performing three specific chemical tests
- Distinguishing diffusion from osmosis

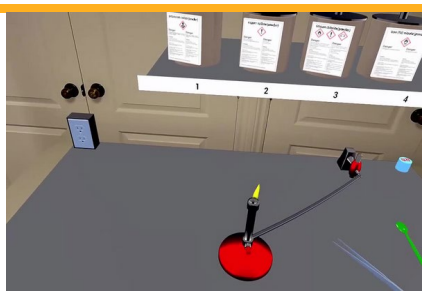
WHAT STUDENTS DO

- Prepare the controls — set up positive controls in wells A and D and tube G, heating tube G above 70 °C in a 75 °C water bath.
- Build the model cell — soften the dialysis bag in warm water, load 3 mL each of starch, salt and glucose, then immerse it in distilled water.
- Test after 24 hours — retest the surrounding water: Lugol turns blue-black, Fehling's gives a brick-red precipitate and silver nitrate a white one.

Lab page: proteus-vr.com/labslist/osmosis/

005 — Identification of elements through bright flames

IB Programme	Chemistry — Atomic structure
Secondary Programme	DP Chemistry
Syllabus Reference	The nuclear atom, periodic table
NGSS (HS)	HS-PS1-1; HS-PS4-3 · SEP 4, SEP 8 · CCC 1
NGSS (MS)	MS-PS1-1
Summary	Flame tests and element identification



OVERVIEW

Every element, when its atoms are given enough energy, emits light at a set of wavelengths that belongs to it alone. That fact underpins a surprising amount of modern science: it is how the composition of stars is determined without leaving Earth, how helium was discovered in the Sun's spectrum decades before it was found on our own planet, and how metal contamination is measured in drinking water and industrial effluent today. The flame test is the oldest and simplest application of the principle. Heating a metal salt in a burner flame supplies energy to the metal's outermost electrons, lifting them into higher-energy orbitals. The excited state is unstable, and within nanoseconds the electron falls back, releasing the energy difference as a single photon. Because the allowed energy levels of an atom are fixed and characteristic, the photon's energy — and therefore the colour of the light — is a signature of the element that produced it.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment and safe handling of an open flame
- Correct execution of a flame test
- Interpreting an emission colour as evidence
- Connecting colour to atomic structure
- Recognising the limits of a qualitative method

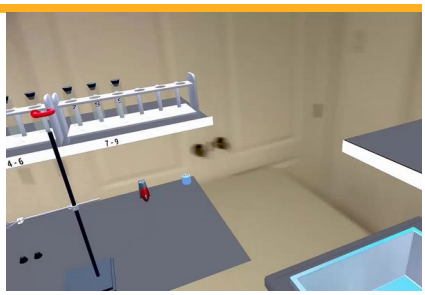
WHAT STUDENTS DO

- Test the powders — light the burner and hold spatula samples of substances 1 to 4 in the flame, one at a time.
- Test the magnesium — grip the magnesium ribbon with tweezers and expose it to the flame; it burns with a brilliant white light.
- Identify the samples — match the colors: lilac for potassium iodide, green for copper sulfate, gold-orange for iron nitrate, crimson for lithium chloride.

Lab page: proteus-vr.com/labslist/identification-of-elements-using-luminous-flames/

006 — Gas Identification

IB Programme	Chemistry — States of matter
Secondary Programme	DP Chemistry
Syllabus Reference	Ideal gases, gas laws
NGSS (HS)	HS-PS1-3 · SEP 4, SEP 6 · CCC 1, CCC 6
NGSS (MS)	MS-PS1-2
Summary	Chemical reactions and gas recognition



OVERVIEW

Identifying a gas is one of the oldest problems in chemistry, and it is still a live one: mine and tunnel crews test the air before entering, brewers and winemakers monitor the carbon dioxide their fermentations produce, and hospitals verify the contents of every gas line before it reaches a patient. Most gases are colourless and odourless, so appearance is no help — a gas must be identified by how it behaves. Three classical tests, together, distinguish the most common laboratory gases. A burning splint probes whether the gas is itself flammable: hydrogen ignites with a sharp pop, while carbon dioxide smothers the flame. A glowing splint probes whether the gas supports combustion better than air: only oxygen relights the ember. And limewater — a saturated solution of calcium hydroxide — detects carbon dioxide specifically, turning milky as insoluble calcium carbonate forms. No single test is conclusive on its own, but the pattern of all three results is unique to each gas. In this laboratory you will apply all three tests to three unknown gases, each supplied in three stoppered test tubes, record the outcome of every trial, and deduce the identity of each gas from the combined evidence.

OBJECTIVES

- Familiarization with the laboratory environment
- Safe handling of gases and open flames
- Correct execution of the three classical gas tests
- Systematic observation and deduction
- Connecting observations to chemical properties

WHAT STUDENTS DO

- Burning splint test — clamp a tube of each gas upside down, unstopper it and insert a lit splint, recording the reaction.
- Glowing splint test — extinguish a splint so it still glows and insert it into a second tube; it relights only in oxygen.
- Limewater test — measure 15 mL of limewater, pour it into a third tube of each gas, restopper and shake; CO_2 turns it milky.

Lab page: proteus-vr.com/labslist/gas-identification/

007 — Separation of Solid and Liquid Products

IB Programme	Chemistry — States & Properties of Matter
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 1.1 – Particulate nature of matter
NGSS (HS)	HS-PS1-3 · SEP 3 · CCC 6
NGSS (MS)	MS-PS1-2
Summary	Filtration and separation techniques

OVERVIEW

Separating a solid from a liquid is among the most common operations in all of applied chemistry. Water treatment plants let sediment settle out of raw water before filtering what remains; mining operations decant and filter enormous volumes to recover valuable minerals; and in the pharmaceutical industry, nearly every synthesis ends with a precipitate that must be cleanly separated from the solution that produced it. The two techniques used everywhere for this task are the ones in this laboratory: decantation and filtration. Both exploit physical differences between the phases of a heterogeneous mixture, so neither changes the chemical identity of anything. Decantation uses density: a suspended solid denser than the liquid settles under gravity, and once it has collected at the bottom, the liquid above — the supernatant — can simply be poured off. Filtration uses particle size: liquid molecules pass freely through the microscopic pores of a paper filter, while solid particles, enormously larger, are held back. In this laboratory you will separate a mixture of cobalt (II) hydroxide and water in two stages — first by decanting the settled mixture, then by filtering the remaining deposit — and see for yourself why the two methods are used in sequence rather than alone.

OBJECTIVES

- Familiarization with the laboratory environment
- Careful manipulation of liquids and suspensions
- Mastery of the vocabulary of separation
- Understanding the principle behind each technique
- Sequencing separation methods

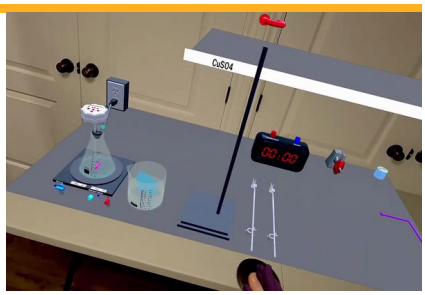
WHAT STUDENTS DO

- Decant the mixture — after the cobalt(II) hydroxide has settled for five minutes, gently pour the water into a second beaker.
- Set up the filtration — seat the funnel in the mouth of the 250 mL Erlenmeyer flask and fit the paper filter inside it.
- Collect filtrate and residue — top the residue beaker up to 100 mL with distilled water and pour it slowly through the filter.

Lab page: proteus-vr.com/labslist/separation-of-solid-and-liquid-products/

008 — Product separation using boiling point 1

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 1.3–1.5 – Electron configurations, gases
NGSS (HS)	HS-PS1-3 · SEP 3, SEP 5 · CCC 5, CCC 7
NGSS (MS)	MS-PS1-4
Summary	Distillation and phase change observation



OVERVIEW

Distillation is the workhorse separation technique of the chemical world. Refineries use it on a colossal scale to split crude oil into fuels, desalination plants use it to win fresh water from the sea, and distillers of every tradition have used it for centuries to concentrate alcohol. Wherever two components of a liquid mixture differ in how readily they vaporise, distillation can pull them apart. The principle is a difference in boiling points. When a solution of a non-volatile solid is heated, only the solvent boils: its molecules escape as vapour while the dissolved solid, whose own boiling point lies hundreds of degrees higher, stays behind. Led away and cooled, the vapour condenses back into liquid — now free of the solute it left in the flask. Heating drives the phase change from liquid to gas; cooling reverses it; and the solute, unable to make either journey, is separated from its solvent. In this laboratory you will separate a copper sulfate solution into its two constituents: the water will be boiled off, condensed in a test tube chilled by an ice bath, and recovered as distillate, while the copper sulfate remains in the Erlenmeyer flask as a solid residue. You will assemble the full apparatus yourself, control the heating, and watch both halves of the separation happen at once.

OBJECTIVES

- Familiarization with the laboratory environment
- Assembly of a distillation apparatus
- Controlled heating of a solution
- Mastery of the vocabulary of distillation
- Understanding the physics of the separation

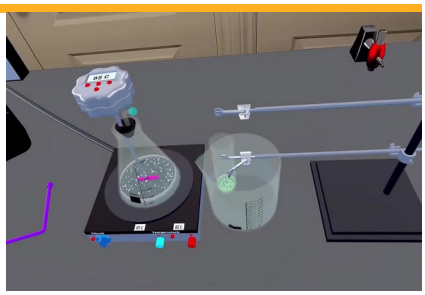
WHAT STUDENTS DO

- Set up the flask — pour 60 mL of 1 M copper sulfate into a 250 mL Erlenmeyer flask, add a stir bar and fit the stopper.
- Build the condenser — half-fill the 500 mL ice beaker with cold water and clamp an empty test tube in it, linked by the connector.
- Distill and observe — heat to 105 °C, confirm the 100 °C plateau, and stop when only the blue copper sulfate residue remains.

Lab page: proteus-vr.com/labslist/product-separation-using-boiling-point-1/

009 — Product separation using boiling point 2

IB Programme	Chemistry — Energy and Systems
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 1.5 – Ideal gases
NGSS (HS)	HS-PS1-3 · SEP 3, SEP 5 · CCC 5
NGSS (MS)	MS-PS1-4
Summary	Two-stage distillation of an ethanol solution



OVERVIEW

When the two components of a mixture are both liquids, separation becomes a subtler problem than pulling a solid out of water — and a far more important one. The petrochemical industry runs on it, spirits distillers have practised it for a thousand years, and pharmaceutical and perfume chemistry depend on it daily. The technique is distillation: exploiting the fact that different liquids boil at different temperatures. Ethanol boils at 78.37 °C, water at 100 °C. Heat a mixture of the two and the vapour that rises is richer in ethanol than the liquid it came from, because at any temperature the more volatile component escapes the liquid more readily. Capture and condense that vapour and you hold a fraction enriched in ethanol; keep heating, and once the ethanol is largely gone the temperature climbs until the water distils in its turn. A thermometer tracks the whole story — plateaus in the temperature curve mark the phase changes, and the rise between them signals the changeover from one component to the other. In this laboratory you will separate a 25% v/v ethanol–water solution — the strength of a typical mouthwash — by two-stage simple distillation, collecting an ethanol-rich first fraction in one test tube at 85 °C and the remaining water in a second at 105 °C.

OBJECTIVES

- Familiarization with the laboratory environment
- Assembly and reconfiguration of a distillation apparatus
- Controlled two-stage heating
- Reading a temperature–time curve
- Understanding volatility and mixtures

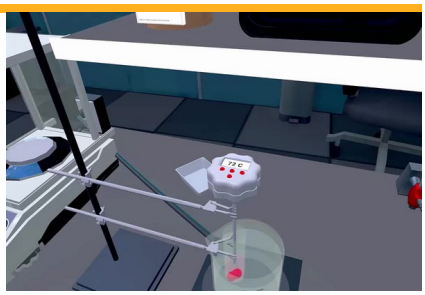
WHAT STUDENTS DO

- Assemble the setup — measure about 70 mL of 25% v/v ethanol into a 250 mL Erlenmeyer flask, add a stir bar and stopper it.
- Collect the first fraction — set the plate to 85 °C and collect the ethanol-rich condensate in test tube 1 in the ice bath.
- Collect the second fraction — switch to test tube 2, raise the plate to 105 °C until the flask is dry, then cool it to 15 °C.

Lab page: proteus-vr.com/labslist/product-separation-using-boiling-point-2/

010 — Melting point and density

IB Programme	Chemistry — States of Matter
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 2.1–2.4 – Bonding and structure
NGSS (HS)	HS-PS1-3 · SEP 4, SEP 5 · CCC 1, CCC 6
NGSS (MS)	MS-PS1-1
Summary	Material identification using melting point and density



OVERVIEW

How do you tell one substance from another when both are white, odourless solids? Not by appearance — by measurement. Every pure substance carries a set of physical properties that do not depend on how much of it you have: its density, its melting point, its boiling point. These are called intensive properties, and they work like a fingerprint. Quality-control laboratories verify raw materials this way, forensic scientists identify unknown samples this way, and geologists classify minerals this way. Density is the ratio of a sample's mass to its volume — how much matter is packed into each millilitre. The melting point is the temperature at which the solid's ordered structure collapses into liquid, and it stays fixed while melting is under way: the heat flowing in is consumed breaking the structure, not raising the temperature, which is why a melting substance shows a plateau on a temperature–time graph. In this laboratory you will measure both properties for paraffin wax. First you will weigh a sample and determine its volume by water displacement, giving its density; then you will melt a weighed sample in a water bath, following the temperature on the tablet's graph to catch the melting plateau.

OBJECTIVES

- Familiarization with the laboratory environment
- Correct use of the electronic balance
- Measuring the volume of an irregular solid
- Determining a density
- Measuring a melting point
- Understanding intensive properties

WHAT STUDENTS DO

- Weigh the sample — tare the weighing boat and weigh five pieces of paraffin; expect 21 to 26 g.
- Measure volume by displacement — slide the pieces into 20 mL of water and record the rise; expect 24.7 to 30.6 mL.
- Melt and monitor — heat 21.25 g (18 mL) of paraffin in a test tube in a 6 °C bath, hot plate set to 85 °C.

Lab page: proteus-vr.com/labslist/melting-point-and-density/

011 — Density

IB Programme	Chemistry — Measurement, Change
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 1.1 – Matter properties
NGSS (HS)	HS-PS1-3 · SEP 4, SEP 5 · CCC 3
NGSS (MS)	MS-PS1-1
Summary	Determining the density of an unknown gas

OVERVIEW

Gases have density, just as solids and liquids do — but so little of it that measuring it takes ingenuity. The answer matters more than it might seem: propane leaking from a tank does not drift away but pools invisibly at floor level, precisely because it is denser than air; helium lifts a balloon because it is lighter; and a gas's density is often the quickest clue to its identity, since at a given temperature and pressure it is fixed by the mass of the gas's molecules. The difficulty is practical: 100 mL of a typical gas weighs a fifth of a gram, far too little to place on a balance by itself. The classical solution is weighing by difference. Weigh a sealed container empty — genuinely empty, evacuated — then weigh it again filled with the gas; the difference is the mass of the gas alone, and dividing by the volume gives the density. Because both weighings are made with the syringe at the same setting, everything else about the apparatus cancels out of the subtraction. In this laboratory you will measure the density of an unknown gas: first weighing a syringe assembly holding a 100 mL vacuum, then refilling it with 100 mL of the gas from its cylinder and weighing again. From the 0.18 g difference you will compute the density — and from the density, reason your way to what the gas is.

OBJECTIVES

- Familiarization with the laboratory environment
- Manipulating a gas quantitatively
- Precision weighing and the difference method
- Computing and interpreting a gas density
- From density to identity

WHAT STUDENTS DO

- Evacuate the syringe — empty the syringe, fit the canister connector, clamp it shut and pull the plunger to a 100 mL vacuum.
- Weigh the empty assembly — block the plunger with the nail and weigh syringe, connector, clamp and nail; expect 46.45 g.
- Fill with gas and reweigh — admit 100 mL of the unknown gas, reseal and reweigh; the gas adds about 0.18 g, giving 46.63 g.

Lab page: proteus-vr.com/labslist/the-density/

012 — Physical properties and identification of products

IB Programme	Chemistry — Properties of Matter
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 2.4 – From models to materials
NGSS (HS)	HS-PS1-3 · SEP 4, SEP 6 · CCC 1, CCC 6
NGSS (MS)	MS-PS1-1; MS-PS1-2
Summary	Identifying unknowns from boiling point and density

OVERVIEW

No two pure substances share the same set of physical properties. Each has its own boiling point and its own density, and these constants are catalogued in reference tables that chemists consult every day. This is why an unlabelled bottle is never identified by guesswork: measuring one or two well-chosen physical properties and comparing the results against known values is usually enough to name a substance. The same approach is used in quality control, in forensic laboratories, and in checking the purity of manufactured chemicals. Two properties carry this laboratory. The boiling point is the temperature at which a liquid's vapour pressure equals the surrounding atmospheric pressure; while a liquid boils, its temperature stops rising, because the heat supplied is consumed by the change of state rather than by warming the liquid. Density is the ratio of mass to volume, $\rho = m/V$.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment and safe laboratory conduct
- Measurement of volume and mass
- Determination of a boiling point
- Determination of density by water displacement
- Identification of substances from physical properties

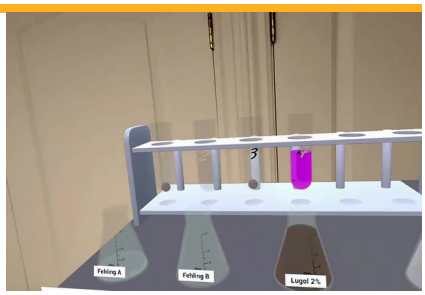
WHAT STUDENTS DO

- Boiling point trial — measure 50 mL of each unknown liquid, set both hot plates to 105 °C and record the temperature change.
- Density by displacement — weigh five pieces of each solid, then collect the overflow from a 500 mL vessel in a 25 mL cylinder.
- Identify the samples — water boils at 100 °C, ethanol at 78 °C; $CaCO_3$ is 14.5 g in 5.4 mL and $Fe(OH)_3$ 63.75 g in 15 mL.

Lab page: proteus-vr.com/labslist/physical-properties-and-product-identification/

013 — Nutrients

IB Programme	Biology — Organisms, metabolism
Secondary Programme	DP Biology
Syllabus Reference	Macronutrients, enzymes
NGSS (HS)	HS-LS1-6 · SEP 4, SEP 6 · CCC 5, CCC 6
NGSS (MS)	MS-LS1-7
Summary	Food chemistry and biochemical reactions



OVERVIEW

Every food is a mixture of biological molecules, and four families dominate: simple sugars, starches, lipids and proteins. Knowing which of them a food contains is the basis of nutrition labelling, of dietary advice, and of quality control in the food industry — and long before instruments existed, chemists established the answer with a handful of colour reactions that are still taught, and still used as quick screening tests, today. Each test works because a reagent reacts with one specific chemical feature and produces a visible change. Fehling's solution is reduced by the free aldehyde group of a reducing sugar, and the copper(II) it contains is converted to brick-red copper(I) oxide. Lugol's iodine slips into the helical coil of a starch molecule and forms an intensely coloured iodine–starch complex. Sudan IV is a fat-soluble dye that abandons the water and dissolves in any lipid droplet present, staining it red. The Biuret reagent, copper(II) in alkaline solution, forms a violet complex with the peptide bonds that link amino acids in a protein. None of these tests is sensitive to anything else, which is what makes the set informative.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment and safe handling of reagents
- Preparation and division of samples
- Avoiding cross-contamination
- Performing the four nutrient tests
- Reading and recording results
- Interpreting colour reactions chemically

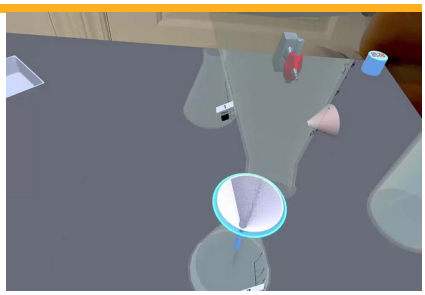
WHAT STUDENTS DO

- Prepare the samples — measure 10 mL of each food into a labeled test tube and place 5 to 10 drops into three microplate wells.
- Carbohydrate tests — add Fehling's A and B and warm the tubes above 70 °C, then add Lugol's iodine to the wells.
- Lipid and protein tests — add Sudan IV, then 1 drop of NaOH with 4 to 5 drops of $CuSO_4$ for the Biuret test.

Lab page: proteus-vr.com/labslist/nutrients/

014 — Heavy metal extraction

IB Programme	Chemistry — Sustainability, human impact
Secondary Programme	DP Chemistry
Syllabus Reference	Precipitation, solubility
NGSS (HS)	HS-PS1-2; HS-ESS3-4 · SEP 3, SEP 6 · CCC 5
NGSS (MS)	MS-PS1-2
Summary	Pollution and chemical remediation



OVERVIEW

Lead and copper reach wastewater from corroding pipework, from spent plating and etching baths, and from the careless disposal of paints and solvents. Neither element is destroyed by dilution or by biological treatment, and both are toxic at low concentration — which is why municipal and industrial treatment plants remove dissolved metals chemically before water is discharged. The standard method is the one used here: add a counter-ion that forms an insoluble salt with the metal, then filter the solid out. The chemistry rests on solubility. A salt precipitates when the product of its ion concentrations exceeds its solubility product K sp ; below that value it stays dissolved. Lead sulfate and copper carbonate are both very sparingly soluble, so adding sulfate removes lead as PbSO 4 and adding carbonate removes copper as CuCO 3 . The order is not arbitrary. Carbonate would precipitate lead as well as copper, so if carbonate were added first the two metals would come out together and could not be separated. Sulfate, by contrast, leaves copper in solution — copper sulfate is freely soluble — so sulfate first, carbonate second, gives two clean fractions. In this laboratory you will treat a 100 mL sample of wastewater containing both metals.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment and safe handling of heavy metals
- Selective precipitation
- Gravimetric filtration technique
- Quantitative treatment of the results
- Assessing the effectiveness of a treatment

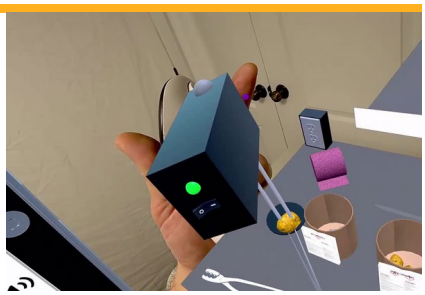
WHAT STUDENTS DO

- Precipitate the lead — weigh a filter paper, measure 100 mL of wastewater into flask 1 and add sodium sulfate; white $PbSO_4$ forms.
- Filter and weigh — filter into flask 2, dry the paper and reweigh it to obtain the lead sulfate mass by difference.
- Repeat for copper — add potassium carbonate to flask 2, then filter and weigh the blue-green basic copper carbonate.

Lab page: proteus-vr.com/labslist/014-heavy-metal-extraction/

015 — Metal properties

IB Programme	Chemistry — Transformation & Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3.1 – Redox & metal activity
NGSS (HS)	HS-PS1-1; HS-PS1-2 · SEP 4, SEP 6 · CCC 1, CCC 6
NGSS (MS)	MS-PS1-2
Summary	Comparing metal reactivity and properties



OVERVIEW

The periodic table is, before anything else, a summary of behaviour. Elements are placed where they are because of how they conduct, how they deform, and what they react with, and those same properties are what tell an engineer whether a material belongs in a wire, a heat sink, a structural beam or a battery. Distinguishing a metal from a non-metal from a metalloid is the first classification a chemist learns, and it is made not by looking up an answer but by testing. Four physical properties and two chemical ones separate the classes. Metals conduct electricity because their outer electrons are delocalised and free to drift through the lattice; the same mobile electrons carry heat, give the surface its reflective lustre, and let the lattice planes slip past one another without breaking, which is malleability. Non-metals hold their electrons in localised covalent bonds and do none of these things. Metalloids sit between: silicon's covalent lattice transmits heat as vibrations perfectly well but releases almost no charge carriers, which is exactly what makes it a semiconductor.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment and safe handling of reactive metals
- Testing physical properties
- Testing chemical properties
- Classifying elements from evidence
- Connecting behaviour to periodic trends

WHAT STUDENTS DO

- Physical property tests — test conductivity with the ECD, judge heat transfer by touch, polish with emery paper and bend with pliers.
- Reaction with acid — place each element in a labeled 50 mL beaker, add drops of 1 M HCl and note effervescence for zinc and iron.
- Reaction with water — add each alkali and alkaline earth metal to 50 mL of distilled water and retest with litmus paper.

Lab page: proteus-vr.com/labslist/metal-properties/

016 — The law of conservation of mass

IB Programme	Chemistry — Chemical reactions
Secondary Programme	DP Chemistry
Syllabus Reference	Stoichiometry, enthalpy
NGSS (HS)	HS-PS1-7 · SEP 5, SEP 6 · CCC 5
NGSS (MS)	MS-PS1-5
Summary	Mass balance experiments

OVERVIEW

The law of conservation of mass states that matter is neither created nor destroyed in a chemical reaction: the atoms present before the reaction are exactly the atoms present after it, only rearranged into different molecules. Antoine Laurent de Lavoisier established the principle in the 1780s by weighing sealed reaction vessels, and it is the reason every chemical equation must be balanced and the reason an industrial chemist can predict the mass of product a process will yield before running it. Demonstrating the law is harder than it sounds, because a reaction that releases a gas appears to lose mass when it is run in an open vessel. The mass has not disappeared — it has simply left the balance pan. Conservation can therefore only be shown in a closed system, one in which every product, gases included, is retained and weighed with the rest. That single experimental requirement is the central idea of this laboratory. You will test the law twice, using two reactions that behave very differently. In Part A, sodium bicarbonate reacts with acetic acid and releases carbon dioxide; the gas is captured in a rubber balloon fitted over the mouth of an Erlenmeyer flask, and a clamp on the neck of the balloon allows the trapped gas to be weighed on its own once the reaction is over.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment
- Building and testing a closed system
- Quantitative weighing technique
- Stoichiometry and the limiting reagent
- Interpreting a mass balance

WHAT STUDENTS DO

- Build a closed system — weigh the balloon, add about 2 g of $NaHCO_3$, pour 25 mL of 1 M acetic acid into the flask and attach the balloon.
- React and reweigh — record the sealed mass, drop the powder into the acid, observe CO_2 bubbling and weigh the system again.
- Precipitation trial — pour 15 mL of 1 M $CaCl_2$ into 15 mL of 1 M Na_2CO_3, note the white $CaCO_3$ and compare beaker masses.

Lab page: proteus-vr.com/labslist/016-the-law-of-conservation-of-mass/

021 — Centrifugation

IB Programme	Biology — Human systems
Secondary Programme	DP Biology
Syllabus Reference	Integration of body systems
NGSS (HS)	HS-LS1-2 · SEP 3 · CCC 6
NGSS (MS)	MS-LS1-2
Summary	Blood composition analysis

OVERVIEW

Centrifugation is a method that uses rapid rotational motion to separate components of a mixture based on differences in density. In clinical laboratories, this technique is essential for the analysis of biological samples such as blood, urine, and cellular suspensions. By accelerating sedimentation, centrifugation allows components that would normally take hours or days to separate under gravity to do so in minutes. Blood is a heterogeneous mixture composed of several elements, including red blood cells, white blood cells, platelets, plasma, and dissolved substances such as proteins and lipids. When centrifuged under controlled conditions, these components separate into distinct layers that can be observed and analyzed. Variations in the appearance or relative proportions of these layers provide valuable diagnostic information. In this laboratory, you will centrifuge a series of blood samples, two of which originate from patients presenting pathological conditions: anemia, characterized by a reduced concentration of red blood cells, and lipemia, characterized by an excess of lipids in plasma.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment
- Operation of centrifugation equipment
- Sample preparation and balancing
- Observation of separated phases
- Clinical interpretation of results

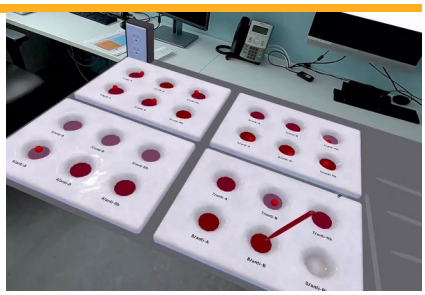
WHAT STUDENTS DO

- Balance the rotor — fill tubes A to D with tap water, cap them and load positions 1 to 4 opposite the blood tubes.
- Run the cycle — load the blood tubes in positions 5 to 8, set 2500 rpm and 5 minutes, then start and wait for a full stop.
- Read the phases — photograph the tubes and record three layers: red cells, a thin buffy coat and plasma.

Lab page: proteus-vr.com/labslist/021-centrifugation/

023 — Blood and blood groups

IB Programme	Biology — Human systems
Secondary Programme	DP Biology
Syllabus Reference	Integration of body systems
NGSS (HS)	HS-LS1-2 · SEP 4, SEP 6 · CCC 4, CCC 6
NGSS (MS)	MS-LS1-3
Summary	Immunity and blood typing exploration



OVERVIEW

Blood typing is one of the oldest and most consequential routine tests in medicine. Karl Landsteiner identified the ABO groups in 1901 after noticing that blood from some people clumped when mixed with blood from others, and the Rh factor was described four decades later. Together the two systems decide whether a transfusion saves a life or destroys the recipient's red cells within minutes, and they are checked before every transfusion, in every pregnancy, and in forensic and paternity work. The test rests on a single molecular idea. The surface of a red blood cell carries inherited sugar and protein markers called antigens: the A antigen, the B antigen, both, or neither, and separately the Rh (D) antigen. A serum containing antibodies against one of these markers — an agglutinin — has two or more binding sites, so when it meets cells carrying its target antigen it bridges them together into visible clumps. This is agglutination: the drop loses its smooth, even red appearance and becomes grainy, with darker specks in a clearing fluid.

OBJECTIVES

- Familiarization with the laboratory environment
- Handling biological samples safely
- Avoiding cross-contamination
- Reading an agglutination reaction
- Determining ABO group and Rh status
- Reasoning about transfusion compatibility

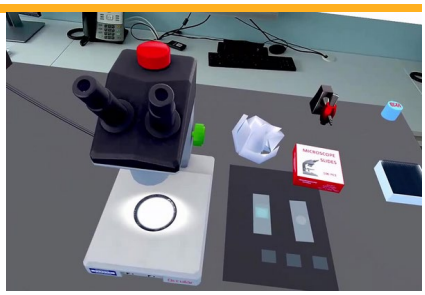
WHAT STUDENTS DO

- Set up the wells — place 5 drops of blood sample 1 into each of three wells labeled anti-A, anti-B and anti-Rh.
- Add the sera — add 2 drops of the matching agglutinin to each well and mix immediately with a clean glass rod.
- Read and repeat — record where clumping occurs, rinse and dry the rod, then repeat with samples 2 through 8.

Lab page: proteus-vr.com/labslist/blood-and-blood-groups/

024 — Observation of animal cells

IB Programme	Biology — Cells
Secondary Programme	DP Biology
Syllabus Reference	Cell structure
NGSS (HS)	HS-LS1-2 · SEP 2, SEP 6 · CCC 4, CCC 6
NGSS (MS)	MS-LS1-1; MS-LS1-2
Summary	Microscopy of animal cells



OVERVIEW

The compound light microscope is the instrument that made cell biology possible, and the cells lining the inside of the human cheek are the classic first specimen. Buccal epithelium is a stratified squamous tissue: its outermost cells are continuously shed, so a sample can be collected without cutting, staining, or sectioning anything. Cytologists still use exactly this material for oral cancer screening and for buccal swabs in genetic testing, which makes it a real diagnostic specimen rather than a teaching convenience. Living animal cells are almost invisible in a light microscope for a simple physical reason: they are mostly water, and their refractive index is barely different from the water they sit in, so they absorb and bend very little of the transmitted light. What a microscopist sees under those conditions is a faint outline and little else. A stain solves the problem by binding selectively to some structures and not others, converting a difference in chemistry into a difference in colour that the eye can read. Lugol's solution — iodine dissolved in potassium iodide — is the standard choice for this preparation: it tints the cytoplasm a pale yellow-brown and picks out the nucleus as a distinctly darker body, and it does so instantly and without heating. In this laboratory you will prepare the same specimen twice and compare the two.

OBJECTIVES

- Familiarization with the laboratory environment
- Operation of a compound light microscope
- Preparation of a wet mount
- Use of a biological stain
- Observation and recording

WHAT STUDENTS DO

- Prepare two slides — place a drop of the cell suspension on each slide, add Lugol's to the second, then apply coverslips.
- Observe unstained cells — view the plain slide at 40× (Plan 4/0.10), refine the focus, then step up to 100× and 400×.
- Compare stained cells — examine the iodine slide at 400×, locate the yellow-stained nucleus and record the differences.

Lab page: proteus-vr.com/labslist/observation-of-animal-cells/

025 — Observation of plant cells

IB Programme	Biology — Cells
Secondary Programme	DP Biology
Syllabus Reference	Cell structure
NGSS (HS)	HS-LS1-2 · SEP 2, SEP 6 · CCC 4, CCC 6
NGSS (MS)	MS-LS1-1; MS-LS1-2
Summary	Microscopy of plant cells

OVERVIEW

Plant cells were the first cells anyone ever saw. In 1665 Robert Hooke put a shaving of cork under a microscope, found it divided into tiny compartments, and borrowed the word cell from the small rooms of a monastery. What made cork legible where animal tissue was not is exactly what makes plant material the better teaching specimen today: a rigid cellulose wall around every cell draws a visible boundary whether the cell is stained or not. Elodea , the aquatic waterweed, is the standard choice. Its leaf is only two cell layers thick, so a whole leaf can be mounted flat without sectioning and light passes straight through it. Inside each cell sit dozens of chloroplasts, dense with chlorophyll and therefore green enough to be seen with no stain at all, while a single large central vacuole occupies most of the volume and presses the cytoplasm and the chloroplasts into a thin layer against the wall. Almost every distinctive feature of a plant cell — wall, chloroplasts, vacuole, an orderly tissue geometry — is visible in one preparation. The nucleus is the exception.

OBJECTIVES

- Familiarization with the laboratory environment
- Operation of a compound light microscope
- Preparation of a wet mount
- Identification of plant cell structures
- Use of a biological stain
- Observation and recording

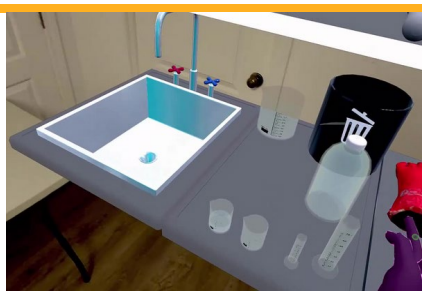
WHAT STUDENTS DO

- Prepare two slides — place a small Elodea leaf on each slide with tweezers, adding water to one and Lugol's iodine to the other.
- Observe living cells — view the water slide at 40×, then 100× and 400×, noting the cell wall and green chloroplasts.
- Locate the nucleus — examine the stained slide at 400× to find the nucleus and note how iodine darkens the chloroplast starch.

Lab page: proteus-vr.com/labslist/observation-of-plant-cells/

026 — Vegetal DNA

IB Programme	Biology — Genetics
Secondary Programme	DP Biology
Syllabus Reference	DNA replication, inheritance
NGSS (HS)	HS-LS3-1 · SEP 1, SEP 3 · CCC 6
NGSS (MS)	MS-LS3-1
Summary	DNA extraction visualization



OVERVIEW

Extracting DNA is the first step of almost every procedure in molecular biology: sequencing a genome, testing a crop variety for a disease-resistance gene, matching a forensic sample or confirming a clinical diagnosis all begin by getting DNA out of cells and into a tube. The chemistry is the same at every scale. A cell keeps its contents behind membranes built from phospholipids, and the DNA inside is a very long polyanion — every phosphate group along its backbone carries one negative charge at neutral pH. A detergent dissolves the membranes and releases what the cell contains; dissolved salt supplies sodium ions that screen those negative charges, so neighbouring strands stop repelling one another; and a cold alcohol, in which DNA is far less soluble than in water, then drives the screened molecules out of solution as a mass large enough to see with the naked eye. Banana is a convenient starting material: the flesh is soft enough to reduce to a paste with a pestle, it contains little fibre, and the cultivated banana is triploid, so every cell carries three sets of chromosomes.

OBJECTIVES

- Familiarization with the laboratory environment
- Handling a toxic reagent
- Preparation of an aqueous solution
- Mechanical disruption of plant tissue
- Gravity filtration
- Alcohol precipitation
- Observation and interpretation of the result

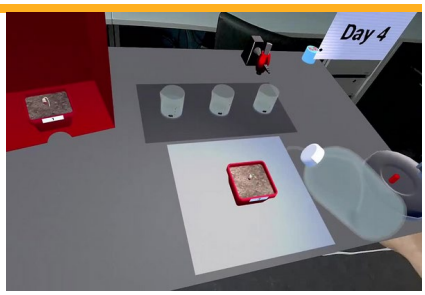
WHAT STUDENTS DO

- Prepare the solution — measure 30 mL of distilled water, weigh 5.4 g of sodium chloride, dissolve it, then add 10 drops of dish soap.
- Break down the cells — crush banana to a homogeneous paste in the mortar, mix in the extraction solution and filter about 15 mL into a test tube.
- Precipitate the DNA — pour 10 mL of cold methanol gently down the tube wall, mix without shaking and watch white stringy DNA form.

Lab page: proteus-vr.com/labslist/vegetal-dna/

027 — Germination

IB Programme	Biology — Cycles and reproduction
Secondary Programme	DP Biology
Syllabus Reference	Reproduction, adaptation
NGSS (HS)	HS-LS1-5 · SEP 3, SEP 4 · CCC 5, CCC 7
NGSS (MS)	MS-LS1-5
Summary	Seed growth and plant development



OVERVIEW

Germination is the point at which a dry, dormant seed becomes a living plant. Water taken up by imbibition reactivates the seed's metabolism, enzymes break down the starch and protein stored in the cotyledons, the radicle emerges and anchors the seedling, and the shoot pushes up towards the surface. None of that requires light: a seed germinates perfectly well in the dark, on the reserves packed into it. What does require light is the next step. Chlorophyll cannot be assembled in darkness, so a seedling that reaches the air without light stays pale, keeps its stem bent in a protective hook, and never opens its leaves; it lives on its reserves until they run out. Given light, the hook straightens, the cotyledons and first leaves expand and turn green, and the plant switches from consuming its reserves to making its own sugar by photosynthesis. Seed companies, growers and greenhouse operators depend on knowing exactly how much light a seedling needs to make that transition, and how quickly. In this laboratory you will soften three bean seeds in water, plant them in three identical numbered pots, and then place each pot in a different light environment: pot 1 inside a closed shoe box, pot 2 on the counter beside the sink in ordinary room light, and pot 3 directly under a switched-on lamp. All three receive the same soil and the same watering.

OBJECTIVES

- Familiarization with the laboratory environment
- Design of a controlled comparison
- Seed preparation and planting
- Daily maintenance and control of time
- Observation and record keeping
- Interpretation of the result

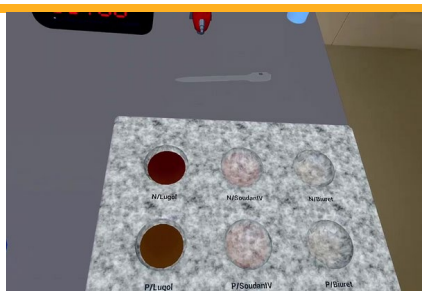
WHAT STUDENTS DO

- Soak and plant — place one bean seed in each of three 50 mL beakers half filled with tap water, then plant them in pots 1 to 3.
- Set the conditions — water all three pots, then place pot 1 in the shoebox, pot 2 on the counter and pot 3 under the lamp.
- Track the growth — advance the clock 24 hours, water all three plants, and repeat until ten simulated days have passed, recording each stage.

Lab page: proteus-vr.com/labslist/germination/

028 — Analysis of stools

IB Programme	Biology — Organisms
Secondary Programme	DP Biology
Syllabus Reference	Metabolism and digestion
NGSS (HS)	HS-LS1-7 · SEP 6, SEP 8 · CCC 5
NGSS (MS)	MS-LS1-7
Summary	Stool biochemistry for suspected malabsorption



OVERVIEW

A stool examination is one of the cheapest and most informative tests in gastroenterology, because what leaves the body undigested says exactly where digestion or absorption has failed. Fat in the faeces points to a pancreas that is not delivering enough lipase or to a damaged intestinal lining; undigested protein points the same way; and sugars that should have been broken down and absorbed in the small intestine turn up in the stool when an enzyme such as lactase is missing. None of these findings requires sophisticated equipment to detect. Each class of nutrient has a colour test that has been in use for well over a century: Fehling's solution turns a brick-red precipitate in the presence of a reducing sugar, iodine turns blue-black with starch, Sudan IV stains lipid droplets red, and copper in alkaline solution turns violet with peptide bonds. In this laboratory you will run all four tests on two samples side by side — sample N from a person whose digestion is normal, and sample P from a patient — and use the difference between the two columns of results to say which nutrient classes the patient is failing to digest. Three of the tests are done in the wells of a microplate; the Fehling's test needs heat, so it is done in test tubes clamped in a water bath on a hot plate.

OBJECTIVES

- Familiarization with the laboratory environment
- Handling of biological material
- Sample handling and layout of an assay
- Operation of a heated water bath
- Use of the four qualitative nutrient tests
- Reading, recording and interpreting results

WHAT STUDENTS DO

- Prepare the samples — measure 10 mL of each stool sample into test tubes N and P, then load 5 to 10 drops into three wells each.
- Test for simple sugars — add equal volumes of Fehling's A and B to each tube, then heat above 70 °C in the 75 °C stirred water bath.
- Run the well tests — add Lugol's iodine, Sudan IV, then NaOH and copper sulfate to the wells and compare the N and P color changes.

Lab page: proteus-vr.com/labslist/observation-of-stools/

029 — Observation of saliva

IB Programme	Biology — Enzymes
Secondary Programme	DP Biology
Syllabus Reference	Enzyme activity
NGSS (HS)	HS-LS1-6 · SEP 3, SEP 4 · CCC 5, CCC 6
NGSS (MS)	MS-LS1-7
Summary	Saliva microscopy with iodine staining

OVERVIEW

Saliva looks like water and is anything but. Roughly 99 % of it is water, and the remaining 1 % does the work: electrolytes that buffer the mouth against acid, mucins that make the fluid slippery, lysozyme and immunoglobulin A that limit bacterial growth, and α-amylase, which begins digesting starch before the food is swallowed. Suspended in that fluid is a population of solid material — flat squamous cells shed from the lining of the mouth, bacteria in enormous numbers, food debris and strands of mucus. A drop of it under a microscope is one of the quickest ways to show a student that a body fluid is a suspension of cells rather than a clear liquid, and it is also a good introduction to the central problem of light microscopy: living cells are transparent, so magnifying them is not enough. You have to give them contrast. In this laboratory you will prepare two slides from the same saliva sample, one plain and one with a drop of Lugol's iodine added, and examine both through the same three objectives, 40×, 100× and 400×. The comparison between the two slides at the same magnification, rather than the magnification itself, is the point of the exercise: the plain slide shows how little is visible without a stain, and the stained slide shows what the stain reveals.

OBJECTIVES

- Operation of a compound microscope
- Understanding of magnification and resolution
- Preparation of a wet mount
- Use of a contrast stain
- Identification of what is in the sample
- Recording and reporting observations

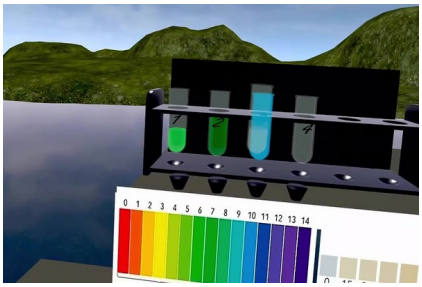
WHAT STUDENTS DO

- Prepare two mounts — place a drop of saliva on each slide, add Lugol's iodine to the second, apply coverslips and blot the excess.
- Step up magnification — observe the unstained slide at 40x with the red objective, then move to 100x and 400x, refocusing each time.
- Compare the slides — examine the stained slide from 100x and record that nuclei appear brown while unstained cells stay faint and colorless.

Lab page: proteus-vr.com/labslist/029-observation-of-saliva/

030 — Chemistry of river water

IB Programme	Biology — Sustainability
Secondary Programme	DP Biology
Syllabus Reference	Ecosystems, sustainability
NGSS (HS)	HS-LS2-7; HS-ESS3-3; HS-ESS3-4 · SEP 4, SEP 7 · CCC 2, CCC 4
NGSS (MS)	MS-LS2-1; MS-ESS3-3
Summary	Water quality testing



OVERVIEW

Water-quality monitoring is one of the most routine analytical jobs in the world: municipal laboratories, environmental agencies and watershed associations all run the same short battery of tests on river, lake and well samples, week after week. Four parameters carry most of the information. The pH fixes which chemical species can exist in the water and how metals behave; the hardness reports the total concentration of dissolved calcium and magnesium, which comes from the rock the water has crossed; the nitrate and phosphate concentrations report how much fertiliser, manure or waste water the catchment is delivering, because these two ions are the nutrients that limit algal growth. Each parameter is measured by a different family of method: potentiometry and an acid–base indicator for pH, a complexometric titration with EDTA for hardness, and two colour-forming reactions read against a printed colour card for the nutrients.

OBJECTIVES

- Familiarization with field sampling
- Use of the pH meter and of colorimetric charts
- Complexometric titration technique
- Colorimetric determination of nutrients
- Quantitative treatment of the data
- Interpretation and laboratory discipline

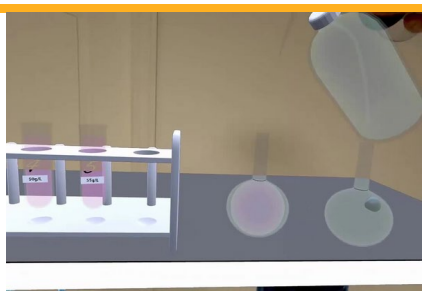
WHAT STUDENTS DO

- Measure pH — transfer 20 mL to test tube 1, add two drops of universal indicator, and confirm the reading with the pH meter.
- Titrate for hardness — buffer test tube 2 above pH 10, add Eriochrome Black T, then add EDTA 1 mL at a time until the color turns.
- Test the nutrients — develop nitrate with reducing agent and Griess reagent, phosphate with ammonium molybdate and ascorbic acid.

Lab page: proteus-vr.com/labslist/030-chemistry-of-river-water/

038 — Preparation of solution by dissolution

IB Programme	Chemistry — Mixtures, States of Matter
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 1.5 – Ideal gases / solutions
NGSS (HS)	HS-PS1-3 · SEP 3, SEP 5 · CCC 5
NGSS (MS)	MS-PS1-4
Summary	Preparing solutions of known mass concentration



OVERVIEW

Preparing a solution of known concentration is the most frequently performed operation in any laboratory. A calibration standard for an instrument, a reagent for a titration, a buffer for a cell culture, an intravenous fluid, a syrup on a production line — all of them are made by the same three-step routine: calculate the mass of solute the target concentration requires, weigh that mass, and bring it to a known final volume. The technique is worth learning carefully, because every quantitative result obtained later rests on the concentration of the solutions used to obtain it. Two things make the routine less obvious than it looks. The first is that concentration can be written in several ways that are numerically different but describe the same quantity: a mass concentration in grams per litre, a percent mass per volume, or a molar concentration in moles per litre. Converting between them correctly is half the exercise. The second is that volumes of liquids and solids are not additive. Dissolving a solid in 100 mL of water does not give 100 mL of solution — it gives slightly more, because the dissolved particles occupy space of their own.

OBJECTIVES

- Calculation of the mass of solute
- Use of the electronic balance
- Volumetric technique
- Dissolution and homogenisation
- Estimating a concentration by colour
- Record keeping

WHAT STUDENTS DO

- Prepare solution A — calculate and weigh 2.5 g of juice crystals for 25 g/L, dissolve in 50 mL and make up to the 100 mL mark.
- Prepare solution B — convert 5% m/v to 50 g/L, weigh 5 g, dissolve and make up to 100 mL in the second volumetric flask.
- Compare — stand both beakers beside the reference solutions in front of the black card; A matches 25 g/L and B matches 50 g/L.

Lab page: proteus-vr.com/labslist/solution-preparation-by-dissolution/

039 — Changing the solubility of a solid

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 1 – Thermodynamics
NGSS (HS)	HS-PS1-5 · SEP 4 · CCC 2, CCC 5
NGSS (MS)	MS-PS1-4
Summary	Temperature influence on solubility

OVERVIEW

Solubility is the property that decides whether a substance can be used in solution at all, and it is the first number a chemist looks up before designing a preparation, a purification or a formulation. It sets how concentrated a reagent can be made, whether a drug can be given as a syrup or must be given as a tablet, why sugar can be dissolved into hot tea but not into iced tea, why limescale forms in a kettle rather than dissolving away in it, and why a recrystallisation works: a solid is dissolved in hot solvent and recovered pure when the solution cools and the solubility falls back. Two factors decide the answer. The first is the chemical nature of the solute and the solvent — the rule of thumb that like dissolves like , which in practice means that a solvent dissolves a solute when the interactions it can offer are strong enough to pay for breaking apart the solid. Water, with its very high dielectric constant and its ability to hydrogen bond, is an excellent solvent for ions and for small molecules covered in hydroxyl groups, and a poor one for a polymer whose chains are hydrogen bonded to each other or for a salt whose lattice is held together too tightly. The second factor is temperature.

OBJECTIVES

- Recognising and reaching saturation
- The effect of temperature
- The effect of the chemical nature of solute and solvent
- Operation of the apparatus
- Observation, recording and honest interpretation

WHAT STUDENTS DO

- Saturate the solution — add 10 g portions of salt to 100 mL of cold water up to 30 g, then 2 g at a time until saturation.
- Heat and observe — set the hot plate to 75 °C and record the temperature at which the accumulated salt fully dissolves.
- Repeat with other solids — repeat with glucose, calcium carbonate, sodium bicarbonate and starch; the last two settle without dissolving.

Lab page: proteus-vr.com/labslist/change-in-the-solubility-of-a-solid/

040 — Precipitation

IB Programme	Chemistry — Chemical Change
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3.2 – Electron transfer reactions
NGSS (HS)	HS-PS1-2 · SEP 6 · CCC 5
NGSS (MS)	MS-PS1-2
Summary	Formation of precipitates from ionic reactions

OVERVIEW

Precipitation is the simplest way to pull a dissolved ion out of solution: two clear liquids are combined, and a compound that will not dissolve appears as a solid suspended in the mixture. Water-treatment plants use it to strip phosphate and heavy metals from effluent, analytical laboratories use the very reaction studied here to determine calcium gravimetrically, and it is the same chemistry that builds kidney stones, which are largely calcium oxalate. A precipitate forms because every ionic compound has a solubility limit. When mixing two solutions pushes the product of the ion concentrations past that limit, the excess leaves the solution as a solid, while the ions that pair into a soluble compound stay dissolved and invisible. What makes a precipitation reaction useful for teaching is that nothing is created or destroyed when it happens. The solid is new, but its atoms were already in the beaker; only their partners have changed. In this laboratory you will weigh an empty 50 mL beaker and an empty 10 mL graduated cylinder, measure 5 mL of 0.2 M calcium chloride and 5 mL of 0.2 M ammonium oxalate, weigh each solution in its own container, pour them together, stir for five seconds and watch a white solid appear, then weigh the beaker one last time.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of the analytical balance
- Measurement of liquid volumes
- Preparation and combination of reagent solutions
- Observation of a precipitation reaction
- Quantitative interpretation of the results

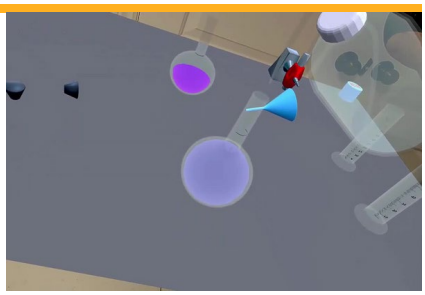
WHAT STUDENTS DO

- Weigh the empty glassware — record the mass of the empty 50 mL beaker (75 g) and the empty 10 mL graduated cylinder (50 g).
- Measure and weigh the reagents — weigh the beaker holding 5 mL of 0.2 M $CaCl_2$ (80.12 g) and the cylinder holding 5 mL of ammonium oxalate (55.12 g).
- Combine and re-weigh — pour the oxalate into the beaker, stir 5 seconds, note the precipitate and confirm the beaker holds 10.24 g of mixture.

Lab page: proteus-vr.com/labslist/precipitation/

041 — Preparation of a solution

IB Programme	Chemistry — Measurement and Concentration
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.1 – Amount of substance
NGSS (HS)	HS-PS1-7 · SEP 5 · CCC 3
NGSS (MS)	MS-PS1-1
Summary	Dissolution and dilution to a target concentration



OVERVIEW

Preparing a solution of a stated concentration is the most common operation in a chemistry laboratory, and there are only two ways to do it: dissolve a weighed mass of solid and make the volume up to a mark, or take a measured volume of a solution that already exists and dilute it. Analytical laboratories, hospital pharmacies and water-treatment plants all keep concentrated stock solutions and dilute them on the day of use, because a dilution can be carried out more accurately and far more quickly than a weighing. Both routes work for the same reason: concentration is a ratio, the mass of solute divided by the volume of solution, so adding solvent changes the volume and therefore the concentration, but never the amount of solute already present. Potassium permanganate is a useful solute for learning this because its colour reports its concentration: the deeper the violet, the more concentrated the solution. In this laboratory you will prepare one solution by each route and check both against a set of six reference tubes. First you will weigh about 4 g of potassium permanganate, transfer it through a funnel into a 100 mL volumetric flask, dissolve it in distilled water and bring the volume up to the calibration mark, which gives 40 g/L.

OBJECTIVES

- Preparation of a solution by dissolution
- Preparation of a solution by dilution
- Correct use of volumetric glassware
- Concentration calculations
- Colorimetric verification of a result
- Handling a strong oxidiser safely

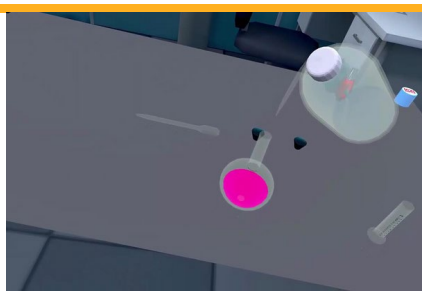
WHAT STUDENTS DO

- Dissolve — weigh 4 g of $KMnO_4$ into the 100 mL volumetric flask, add about 50 mL of water, shake, then make up to the mark.
- Dilute — measure 54.7 mL of the stock into the 250 mL volumetric flask and make up to volume with distilled water.
- Verify — compare each solution with the control tubes against a black card; the stock matches tube 5 and the dilution tube 1.

Lab page: proteus-vr.com/labslist/preparing-a-solution/

043 — Dilutions

IB Programme	Chemistry — Measurement and Change
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.1 – Amount of substance
NGSS (HS)	HS-PS1-7 · SEP 5 · CCC 3
NGSS (MS)	MS-PS1-1
Summary	Preparing dilutions to identify an unknown solution



OVERVIEW

Dilution is how one carefully prepared concentrated solution is turned into the many working strengths that a laboratory, a hospital pharmacy or a bottling plant actually needs. A single stock solution is made up and verified once, and every weaker solution is then obtained from it by measuring out a known volume and bringing that volume up to a known final volume. Disinfectants, intravenous drug doses, buffers, photographic developers and the syrups behind soft drinks are all made this way, because measuring a volume accurately is quicker and far more reproducible than weighing out a small mass of solute afresh every time. The science behind it is a conservation statement: adding solvent changes the volume of a solution and therefore its concentration, but it does not change the amount of solute already in it. If a volume V 1 of a solution at concentration C 1 is diluted to a final volume V 2 , the amount of solute is the same before and after, so C 1 V 1 = C 2 V 2 . The ratio V 2 /V 1 is called the dilution factor, and the concentration falls by exactly that factor. When the solute is coloured, that fall is visible: a more dilute solution absorbs less light and looks paler, which is what makes a set of known dilutions usable as a comparison scale for a sample whose concentration has never been measured.

OBJECTIVES

- Understanding what a dilution does
- Quantitative use of the dilution relation
- Correct use of volumetric glassware
- Concentration, colour and comparison against a reference

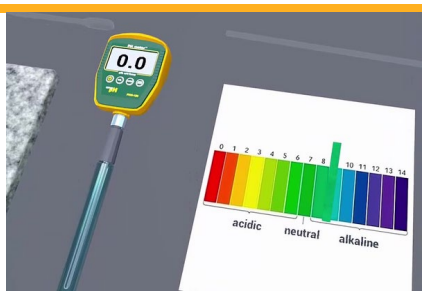
WHAT STUDENTS DO

- Prepare Solution A — measure 10 mL of the 5% V/V stock into a 100 mL volumetric flask and fill to the mark: 0.5% V/V.
- Prepare Solution B — repeat with 2 mL of the stock in the second 100 mL volumetric flask to obtain 0.1% V/V.
- Identify the unknown — stopper, mix gently and compare both flasks with the unknown; the match is Solution A at 0.5% V/V.

Lab page: proteus-vr.com/labslist/dilutions/

046 — pH

IB Programme	Chemistry — Acids and bases
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3.1–3.4
NGSS (HS)	HS-PS1-2 · SEP 3, SEP 4 · CCC 1
NGSS (MS)	MS-PS1-2
Summary	Measuring pH with indicators and a digital meter



OVERVIEW

Almost every chemical process that takes place in water is sensitive to how acidic or basic that water is. Blood is held within about a tenth of a pH unit of 7.4, soil pH decides which crops will grow, and industrial effluent is regulated on pH before it may be discharged. Measuring pH reliably, and knowing how far to trust a given measurement, is one of the most widely used skills in analytical chemistry. The quantity itself is defined logarithmically: pH = −log 10 [H +], where [H +] is the hydrogen ion concentration in moles per litre. Because the scale is logarithmic, one whole unit represents a tenfold change in acidity — a solution at pH 3 carries a hundred times as many hydrogen ions as one at pH 5. Pure water at 25 °C sits at pH 7, the point where [H +] and [OH −] are both 10 −7 mol/L. This laboratory uses three methods in increasing order of precision. Litmus paper answers only whether a solution is acidic or basic. A universal indicator produces a colour that can be matched against a chart to within roughly one pH unit.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of protective equipment
- Choosing an appropriate measurement method
- Correct operation of a pH meter
- Preparing a solution from a weighed solid
- Quantitative interpretation of the pH scale
- Predicting whether a dissolved salt will be acidic, basic or neutral

WHAT STUDENTS DO

- Test with papers — measure 20 mL of each liquid into a 50 mL beaker and dip red litmus, blue litmus and pH paper.
- Use universal indicator — transfer each liquid to a well of the well plate, add one drop of universal indicator and read the color.
- Measure with the pH meter — read the three liquids (pH 2.4, 13 and 7), then dissolve 1.8 g ammonium sulfate in 100 mL and measure (≈4.9).

Lab page: proteus-vr.com/labslist/ph/

047 — Acid-base titration 1

IB Programme	Chemistry — Chemical Reactions
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3 – Acid–base neutralization
NGSS (HS)	HS-PS1-2; HS-PS1-7 · SEP 3, SEP 5 · CCC 3
NGSS (MS)	MS-PS1-2
Summary	Colorimetric determination of pH in water

OVERVIEW

Colorimetry is the cheapest way to measure a chemical quantity: add a reagent that changes colour with the quantity you want, then match the result against a set of references of known value. It needs no power, no calibration and no glassware beyond a tube, which is why it is still the standard method for testing swimming pools and aquariums, for field surveys of lakes and rivers, and for the dipsticks used in clinics. Its limitation is equally plain — the answer is only as good as the eye reading it, and only as fine as the spacing of the references. The quantity being measured here is pH, defined as pH = −log[H 3 O +], so that each whole unit of pH is a tenfold change in the concentration of hydronium ions. A universal indicator is not one dye but a blend of several weak acids, each of which changes colour over a different, narrow band of pH. Because their acid dissociation constants are staggered, the blend as a whole changes colour progressively from red through yellow and green to blue across the range of about pH 3 to pH 10, and that colour can be used as a stand-in for a measurement of [H 3 O +] that would otherwise need an electrode. In this laboratory you will build the reference scale yourself rather than being handed one.

OBJECTIVES

- Understanding pH as a logarithmic scale
- Building and using a colorimetric reference scale
- Handling the indicator and the glassware
- Cross-checking one method against another
- Judging the limits of a visual method

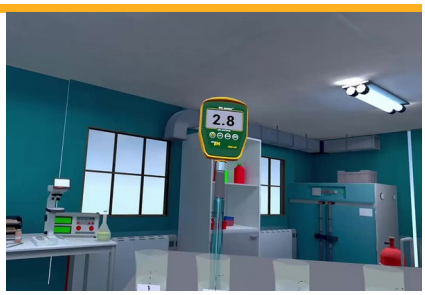
WHAT STUDENTS DO

- Prepare the scale — pour 25 mL of the pH 3 to pH 7 standards into test tubes 1 to 5, add 5 drops of indicator and mix.
- Test the lake water — treat 25 mL of lake water in tube 6 the same way, then match its color to the wall chart scale.
- Extend and verify — if the sample reads above 7, prepare pH 8 and 9 in tubes 7 and 8, then check every tube with the pH meter.

Lab page: proteus-vr.com/labslist/acid-base-titration-1/

048 — The pH of strong and weak acids

IB Programme	Chemistry — Energy, Change
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3.1 – Acid–base equilibrium
NGSS (HS)	HS-PS1-5 · SEP 4, SEP 6 · CCC 1
NGSS (MS)	MS-PS1-2
Summary	Comparison of strong and weak acids



OVERVIEW

Two solutions can hold the same amount of acid per litre and still be very different in how acidic they are. Water treatment plants, food producers, aquarium keepers and clinical laboratories all depend on that distinction: the label on a bottle states a concentration, but what corrodes a pipe, curdles a protein or kills a fish is the concentration of hydronium ion actually present in the liquid. Choosing an acid, and deciding how much of it to use, therefore means knowing whether it gives up its protons completely or only slightly. An acid dissolved in water transfers a proton to a water molecule. A strong acid such as hydrochloric acid does this to completion, so every mole dissolved delivers a mole of hydronium ion. A weak acid such as ethanoic acid — acetic acid, the acid of vinegar — reaches an equilibrium instead: at any moment only a small fraction of its molecules have released their proton, and that fraction depends on how dilute the solution is. The pH scale, pH = −log[H 3 O +], places both cases on the same axis, and a pH meter reads that axis directly by measuring the potential developed across a glass electrode. In this laboratory, you will build a series of three ethanoic acid solutions by serial dilution — 1 mol/L, 0.1 mol/L and 0.01 mol/L — each one made from the previous one by transferring 5 mL with a volumetric pipette into a 50 mL graduated cylinder and topping up to the mark with distilled water. A fourth beaker receives hydrochloric acid at 0.10 mol/L, the same concentration as the second ethanoic acid solution.

OBJECTIVES

- Serial dilution technique
- Use of the pH meter
- Distinguishing concentration from acidity
- Quantitative interpretation of a pH reading
- Safe handling and disposal of acids

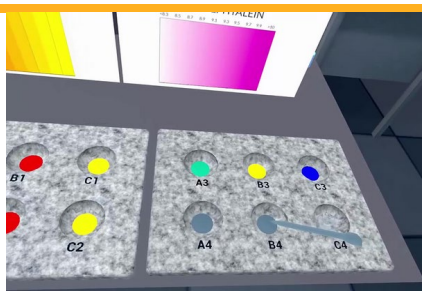
WHAT STUDENTS DO

- Prepare the stock — half-fill beaker 1 with 1 mol/L acetic acid (CH_3COOH), then pipette 5 mL into the 50 mL graduated cylinder.
- Dilute in series — make up to 50 mL with distilled water for beaker 2, repeat for beaker 3, and half-fill beaker 4 with 0.10 mol/L HCl.
- Measure and record — read the pH of all four beakers, rinsing and drying the electrode between readings; expected 2.37, 2.87, 3.37 and about 1.

Lab page: proteus-vr.com/labslist/the-ph-of-strong-and-weak-acids/

049 — Using pH indicators

IB Programme	Chemistry — Observation, Change
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3 – Indicators & buffers
NGSS (HS)	HS-PS1-2 · SEP 4 · CCC 1
NGSS (MS)	MS-PS1-2
Summary	Colorimetric pH measurement



OVERVIEW

An acid-base indicator is a dye that wears one colour in acid and another in alkali. Swimming-pool test kits, soil kits, aquarium kits and the universal paper in every school laboratory all work this way, and so does the endpoint of a titration. What makes an indicator useful is also what limits it: a single dye answers only one question — is the pH above or below my transition range? — so a single well can never give a pH, only an inequality. Put several dyes with different ranges alongside one another, however, and the inequalities close in on each other from both sides. Each dye behaves this way because the dye is itself a weak acid. Its protonated form HIn and its deprotonated form In − absorb light differently, and the two are in equilibrium: HIn + H 2 O ⇌ In − + H 3 O + . Rearranging the equilibrium expression gives pH = pK In + log([In −]/[HIn]), so the ratio of the two coloured forms is fixed by the pH alone. The eye stops distinguishing a mixture from the pure form at a ratio of roughly one to ten, which is why every indicator changes over a band about two pH units wide, centred on its own pK In , and shows a single flat colour on either side of that band.

OBJECTIVES

- Working with a well plate
- How an indicator works
- Reading a colour as an inequality
- Combining evidence from several tests
- Recording and reporting

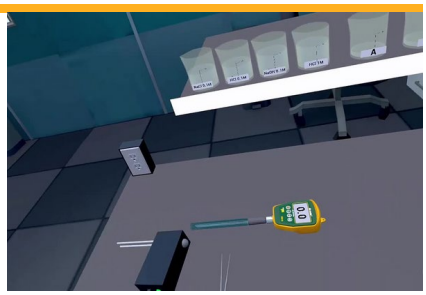
WHAT STUDENTS DO

- Load the plates — put 5 drops of unknown solutions 1, 2 and 3 into every well of columns A, B and C respectively.
- Add the indicators — add 2 drops of methyl orange to row 1, methyl red to row 2, bromothymol blue to row 3 and phenolphthalein to row 4.
- Record and deduce — capture the plate image with the tablet, then bracket each pH from the four transition ranges: about 7, 3 and 9.

Lab page: proteus-vr.com/labslist/using-ph-indicators/

050 — Conductivity and pH

IB Programme	Chemistry — Energy and Matter
Secondary Programme	DP Chemistry
Syllabus Reference	Structure 2.4 – Bonding and materials
NGSS (HS)	HS-PS1-2 · SEP 4 · CCC 2
NGSS (MS)	MS-PS1-2
Summary	Acids, bases and salts: conductivity, pH and dilution



OVERVIEW

Sorting an unknown liquid into acid, base or salt is the first thing an analyst does with it, and the three tests used here are the oldest in the trade. A pair of litmus papers costs almost nothing and answers the question in seconds. A bulb wired in series with two electrodes dipped in the liquid shows whether the liquid carries ions at all. A strip of magnesium fizzes in acid and sits inert in everything else. Between them these tests separate a salt from an acid from a base without a single instrument reading, which is why they survive in water-quality field kits and in school laboratories alike. What the three tests respond to is different in each case, and that is the point of running all three. Litmus is a dye whose colour depends on pH, so it reports the hydronium concentration. The bulb responds to mobile ions, and every soluble ionic compound supplies them whether it is acidic, basic or neutral — so conductivity separates ionic solutions from molecular ones, not acids from bases. Magnesium responds only to hydronium ion, being oxidised to Mg 2+ while H 3 O + is reduced to hydrogen gas. Three tests, three different questions; only their combination identifies a solution.

OBJECTIVES

- Classifying a solution from evidence
- Handling the instruments
- Litmus and pH paper as indicators
- Conductivity and dissolved ions
- Dilution and the logarithmic pH scale
- Safety and disposal

WHAT STUDENTS DO

- Test conductivity — pour 10 mL of 0.1 M NaCl, HCl and NaOH into beakers A, B and C and test each with the conductivity detector.
- Test acidity and reactivity — check red and blue litmus, pH paper and a magnesium ribbon; A reads 7, B 1-2 and C 12-13, and only B fizzes.
- Dilute and measure — dilute 10 mL of 1 M HCl to 30, 60 and 100 mL, and 1 mL to 100 mL; pH 0.5, 0.8, 1.0, 2.0.

Lab page: proteus-vr.com/labslist/conductivity-and-ph/

051 — Stoichiometry

IB Programme	Chemistry — Chemical reactions
Secondary Programme	DP Chemistry
Syllabus Reference	Stoichiometry, reactity
NGSS (HS)	HS-PS1-7 · SEP 5, SEP 6 · CCC 5
NGSS (MS)	MS-PS1-5
Summary	Quantitative chemical relationships

OVERVIEW

Stoichiometry is the arithmetic of chemistry: the set of rules that lets a chemist predict, before anything is mixed, exactly how much product a reaction will make. A pharmaceutical plant uses it to size a batch, a water-treatment operator uses it to dose a coagulant, and an engine designer uses it to set an air-fuel ratio. The rules follow from a single fact, the conservation of matter — a reaction rearranges atoms but never creates or destroys them — so the coefficients of a balanced equation fix the ratio in which substances combine. That ratio is a ratio of moles, not of grams and not of millilitres, which is why every stoichiometric calculation passes through the mole on its way from what is measured out to what is predicted. This laboratory puts that prediction to the test on a neutralization. Sulfuric acid is diprotic: each formula unit can release two protons, so it requires two moles of sodium hydroxide for every one of its own, and the balanced equation reads H 2 SO 4 (aq) + 2 NaOH(aq) → Na 2 SO 4 (aq) + 2 H 2 O(l). Both products are invisible at the moment they form — the sodium sulfate stays dissolved and the new water simply joins the water already there — so the only way to see what was made is to take the solvent away.

OBJECTIVES

- Interpreting a balanced chemical equation
- Converting between concentration, volume, amount and mass
- Recognising stoichiometric and limiting quantities
- Quantitative laboratory technique
- Isolating a dissolved product
- Comparing a measurement with a prediction
- Safe handling of corrosives and hot equipment

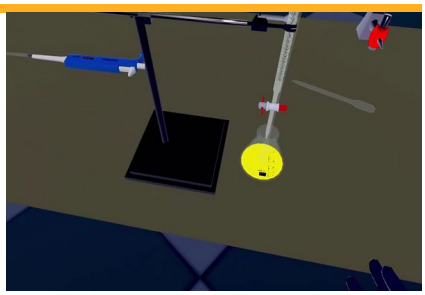
WHAT STUDENTS DO

- Prepare and weigh — place a stir bar and filter paper in the porcelain evaporating dish and record the initial mass, 102 g.
- React and evaporate — pipette 10 mL of 1 M H_2SO_4, add 10 mL of 2 M NaOH, then heat at 105 °C until the water boils.
- Isolate and compare — dry the residue in the oven at 70 °C for 24 h and reweigh; expected yield 1.42 g of Na_2SO_4.

Lab page: proteus-vr.com/labslist/51-stoichiometry-q3-2025/

052 — Acid-base titration 2

IB Programme	Chemistry — Neutralization
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3 – Chemical change
NGSS (HS)	HS-PS1-2; HS-PS1-7 · SEP 3, SEP 5 · CCC 5
NGSS (MS)	MS-PS1-2
Summary	Titration and stoichiometry calculations



OVERVIEW

Titration is the standard way of answering a question that cannot be answered by looking: how much of a dissolved substance is present. A solution of known concentration is added to a measured volume of the unknown, in small controlled amounts, until exactly enough has been added to consume it. The volume needed is read off a burette, and because the balanced equation fixes the ratio in which the two substances react, that volume gives the unknown concentration directly. Water treatment plants, dairies, wineries, swimming-pool operators and clinical laboratories all run titrations daily, and the technique remains the reference method against which faster instrumental analyses are calibrated. The chemistry underneath is neutralization. Hydrochloric acid and sodium hydroxide react one mole to one mole, HCl(aq) + NaOH(aq) → NaCl(aq) + H 2 O(l), so at the moment the acid is exactly consumed the amount of base added equals the amount of acid that was there. That moment is the equivalence point, and because sodium chloride is the salt of a strong acid and a strong base, neither of its ions reacts with water and the solution at equivalence is exactly neutral, pH 7.00. The problem is seeing it.

OBJECTIVES

- The principle of volumetric analysis
- Stoichiometry of neutralization
- Choosing and reading an indicator
- Volumetric glassware technique
- Data handling and precision
- Safety with concentrated corrosives

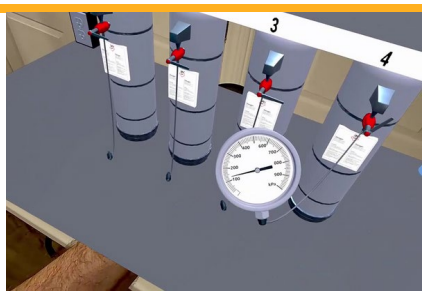
WHAT STUDENTS DO

- Set up the sample — pipette 10 mL of the unknown HCl into the 100 mL Erlenmeyer flask and add 3 drops of bromothymol blue.
- Prepare the burette — half-fill the burette with 2 M NaOH, clear bubbles from the stopcock into a 50 mL beaker, then zero the meniscus.
- Titrate to the endpoint — release one drop (0.05 mL) at a time, mixing after each, until yellow turns green-blue; about 15 drops, 0.75 mL.

Lab page: proteus-vr.com/labslist/052-acid-base-titration-2/

053 — The pressure of gases

IB Programme	Chemistry — States of Matter
Secondary Programme	DP Chemistry / DP Physics
Syllabus Reference	Structure 1.5 – Ideal gases / B.3 Gas laws
NGSS (HS)	HS-PS1-3; HS-PS3-2 · SEP 4, SEP 5 · CCC 5
NGSS (MS)	MS-PS1-4
Summary	Measuring gas pressure with a manometer



OVERVIEW

Pressure is force spread over an area, and for a gas it is the aggregate effect of countless molecules striking the walls of their container. It is one of the few properties of a gas that can be read directly off an instrument, which is why almost every practical dealing with gases begins by measuring it: a diver checking a cylinder before entering the water, a technician charging a refrigeration circuit, a nurse working from a medical oxygen regulator, a mechanic setting tyre pressures. The instrument that does the reading in almost all of these cases is the Bourdon dial gauge, patented by Eugène Bourdon in 1849 and still the standard after a hundred and seventy years. Inside such a gauge is a flattened metal tube bent into an arc and sealed at one end. Raising the pressure inside it makes its oval cross-section rounder, and a tube whose cross-section rounds out has to become straighter, so the sealed end swings outward through a small distance. A linkage and a rack-and-pinion multiply that movement into the sweep of a needle across a dial. Nothing is measured electrically and nothing needs a power supply; the deflection of a piece of metal is doing the work.

OBJECTIVES

- Understanding what pressure is
- Operating a Bourdon dial gauge
- Reading an analogue scale
- Gauge pressure and absolute pressure
- Working with pressure units
- Handling compressed gas safely

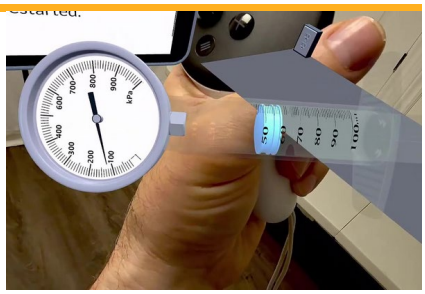
WHAT STUDENTS DO

- Connect the gauge — attach the manometer to the hose of cylinder 1 and open the cylinder valve.
- Read and record — note the needle position to determine the pressure, then close the valve and detach the hose.
- Repeat and compare — test the remaining three cylinders; expected readings are 280, 345, 460 and 130 kPa.

Lab page: proteus-vr.com/labslist/the-pressure-of-gases/

054 — The relationship between the volume and pressure of a gas 1

IB Programme	Chemistry — Energy & Systems
Secondary Programme	DP Chemistry / DP Physics
Syllabus Reference	Structure 1.5 – Ideal gases
NGSS (HS)	HS-PS3-2 · SEP 4, SEP 5 · CCC 1, CCC 5
NGSS (MS)	MS-PS1-4
Summary	Boyle's Law experiment



OVERVIEW

A gas has no fixed size. Squeeze it and it occupies less room; release it and it expands again. Engineers depend on that behaviour every time they design a bicycle pump, the compression stroke of an engine, a scuba regulator, a pneumatic brake or a syringe, and it is how breathing works: the chest cavity enlarges, the pressure inside the lungs falls below the pressure of the room, and air flows in. The quantitative statement behind all of it is Boyle's law — at constant temperature, a fixed quantity of gas satisfies P × V = constant, so pressure and volume are inversely proportional. The microscopic reason is that pressure is nothing more than the accumulated force of molecules striking the walls of their container. Compressing a gas does not make its molecules faster; that would require heating them. It packs the same number of molecules into a smaller space, so more of them reach the wall each second and the force per unit area rises in exact proportion to the crowding. Halve the volume and the pressure doubles; double the volume and it halves.

OBJECTIVES

- Familiarization with the laboratory environment
- Handling a sealed gas system
- Measurement and data recording
- Quantitative treatment of Boyle's law
- Experimental control and validity

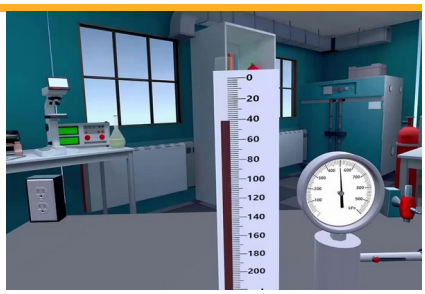
WHAT STUDENTS DO

- Seal the assembly — pull the plunger to exactly 50 mL of air, then connect the syringe to the dial manometer with airtight fittings.
- Expand in steps — pull the plunger in 5 mL steps up to 100 mL, reading the pressure at each step; it falls throughout.
- Compress in steps — return to 50 mL, check the pressure repeats, then push in 5 mL steps to 20 mL, recording each rising reading.

Lab page: proteus-vr.com/labslist/the-relationship-between-the-volume-and-pressure-of-a-gas-1/

055 — The relationship between the volume and pressure of a gas 2

IB Programme	Chemistry — Energy & Systems
Secondary Programme	DP Chemistry / DP Physics
Syllabus Reference	Structure 1.5 – Ideal gases
NGSS (HS)	HS-PS3-2 · SEP 4, SEP 5 · CCC 1, CCC 5
NGSS (MS)	MS-PS1-4
Summary	Advanced Boyle's Law demonstration



OVERVIEW

The Boyle apparatus is the instrument that made the first gas law measurable, and a version of it still stands in most physics and chemistry teaching laboratories. A fixed quantity of air is trapped in a graduated vertical tube above a reservoir of oil; the oil is incompressible and gas-tight, so it behaves as a piston that seals perfectly and slides without friction. Pump air into the reservoir and the oil rises, squeezing the trapped column into a smaller and smaller space while a manometer records the pressure. The same principle governs a bicycle pump, the compression stroke of an engine, an aerosol can, a diver's lungs on ascent and the hydraulic accumulator on a piece of heavy machinery. The relationship being measured is Boyle's law: for a fixed amount of gas at constant temperature, P × V is a constant. Pressure is the accumulated force of molecules striking the walls, so packing the same number of molecules into half the space doubles how often they arrive and doubles the pressure.

OBJECTIVES

- Familiarization with the laboratory environment
- Operating a pressurised system safely
- Measurement and data recording
- Quantitative treatment of Boyle's law
- Critical evaluation of the measurement

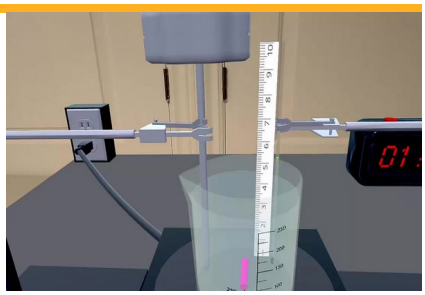
WHAT STUDENTS DO

- Assemble and pressurize — connect the pump hose with the tap open and pump until the gauge reads about 500 kPa with no leaks.
- Stabilize and record — close the tap once the oil stops rising, detach the hose, wait one minute for cooling, then note pressure and volume.
- Release in stages — press the release button to lower the oil column step by step, recording volume in mL and pressure in kPa each time.

Lab page: proteus-vr.com/labslist/the-relationship-between-the-volume-and-pressure-of-a-gas-2/

056 — The relationship between a gas' temperature and its volume

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry / DP Physics
Syllabus Reference	Structure 1.5 – Ideal gases
NGSS (HS)	HS-PS3-2 · SEP 4, SEP 5 · CCC 1, CCC 5
NGSS (MS)	MS-PS1-4
Summary	Charles' Law experiment



OVERVIEW

Heat a gas and it spreads out. That single fact keeps a hot-air balloon in the sky, drives the convection that circulates air in a room, makes bread rise, and is the reason a car's tyre pressure warning light comes on during the first cold morning of the winter. Put quantitatively, it is Charles's law: for a fixed amount of gas held at constant pressure, the volume is directly proportional to the absolute temperature, V / T = constant. The word absolute is doing the work — the proportionality only holds when temperature is counted from the point where molecular motion would cease, not from the freezing point of water. The reason is the same kinetic picture that explains Boyle's law, run the other way. Temperature sets how fast the molecules move. Warm the gas and each molecule arrives at the wall harder and more often, so if it were confined the pressure would rise. Here it is not confined: the gas is free to push its seal along the tube until it has spread out enough that the collisions once again balance the pressure of the room outside. The volume it settles at is proportional to the absolute temperature.

OBJECTIVES

- Familiarization with the laboratory environment
- Preparing a sealed sample
- Measurement and data recording
- Quantitative treatment of Charles's law
- Critical evaluation of the measurement

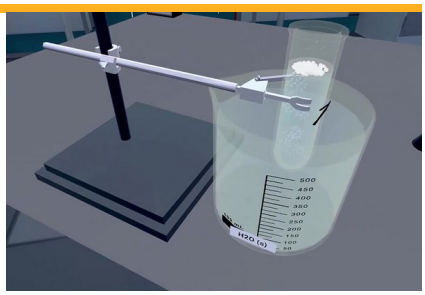
WHAT STUDENTS DO

- Load the capillary — heat the tube in the flame for about 20 seconds, then touch its open end to olive oil on a watch glass.
- Build the setup — clamp the tube and thermometer upright in a 250 mL beaker of ice water, with a ruler behind the tube.
- Heat in steps — raise the hot plate 10 °C at a time with the stirrer running, recording temperature and drop height once stable.

Lab page: proteus-vr.com/labslist/the-relationship-between-a-gas-temperature-and-its-volume/

057 — The relationship between gas solubility and temperature

IB Programme	Chemistry — Change & Systems
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 1 – Energy changes
NGSS (HS)	HS-PS1-5; HS-PS3-2 · SEP 4 · CCC 1, CCC 5
NGSS (MS)	MS-PS1-4
Summary	Temperature dependence of solubility



OVERVIEW

Every carbonated drink is a gas held in a liquid under pressure, and every one of them eventually goes flat. The relationship behind that everyday observation is not a curiosity: it governs how much oxygen a river can hold for its fish, how much carbon dioxide the ocean takes up from the atmosphere, how a brewery carbonates its product, how a treatment plant strips dissolved gas out of boiler feedwater before it corrodes the pipework, and why a blood-gas sample has to be kept cold on its way to the laboratory. In each case the quantity that matters is the concentration of a gas dissolved in a liquid, and two things set it: the pressure of that gas above the liquid, and the temperature of the liquid itself. The governing relationship is Henry's law — at equilibrium, the concentration of a dissolved gas is proportional to its partial pressure above the solution.

OBJECTIVES

- Familiarization with the laboratory environment
- Construction of a controlled comparison
- Operation of stands and universal clamps
- Observation and timing
- Application of Henry's law
- Thermodynamic reasoning
- Critical evaluation of the evidence

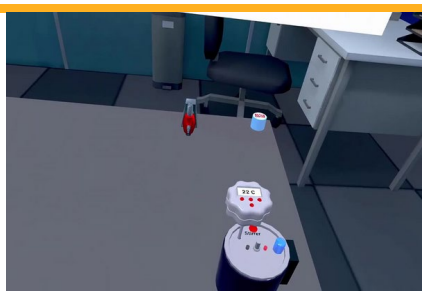
WHAT STUDENTS DO

- Prepare the baths — fill one beaker with ice and cold tap water and a second with hot tap water, then locate the three tubes.
- Set the temperatures — hang tube 1 from a clamp over the cold bath and tube 2 over the hot bath, leaving tube 3 on the rack.
- Open and compare — unstopper the room-temperature, hot, then cold tube and time the effervescence: roughly 25, 20 and 45 seconds.

Lab page: proteus-vr.com/labslist/relationship-between-gas-solubility-and-temperature/

059 — Reaction rate and enthalpy

IB Programme	Chemistry — Reaction kinetics
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 1 – Energy cycles
NGSS (HS)	HS-PS1-4; HS-PS1-5 · SEP 3, SEP 6 · CCC 5, CCC 7
NGSS (MS)	MS-PS1-6
Summary	Calorimetry and reaction enthalpy



OVERVIEW

Calorimetry is how the energy content of anything gets measured — the calorie figure on a food label, the heating value of a fuel, the waste heat a battery gives off while charging, the heat released as concrete cures in a dam wall. The method never changes: run the process inside an insulated vessel whose heat capacity is known, and measure the temperature change of what is inside. Here the process is the reaction of magnesium metal with hydrochloric acid, Mg(s) + 2 HCl(aq) → MgCl 2 (aq) + H 2 (g), which is one of the most strongly exothermic reactions available at school scale. Energy stored in the metallic bonding of magnesium and in the hydrated protons of the acid is released as the reaction proceeds, and because a calorimeter loses very little heat to the room, almost all of it shows up as a rise in the temperature of the liquid. Measuring the size of that rise gives the enthalpy of the reaction. Because the temperature is logged continuously rather than read once at the end, the same experiment answers a second question at the same time: how fast the reaction runs, read from how steeply the temperature climbs and when it levels off.

OBJECTIVES

- Familiarization with the calorimetry bench
- Use of the balance and of a weighing boat
- Operation of the calorimeter
- Following a reaction in real time
- Enthalpy calculation
- Reaction rate
- Critical evaluation of the measurement

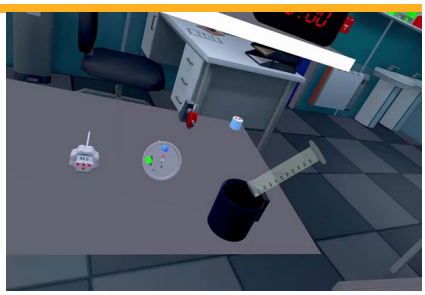
WHAT STUDENTS DO

- Charge the calorimeter — measure 100 mL of 0.2 M hydrochloric acid into the calorimeter and record its initial temperature.
- Add the magnesium — weigh about 0.2 g of magnesium powder, tip it in, fit the lid, and start the stirrer and stopwatch.
- Collect the data — follow the graph to its plateau near 225 seconds; expect about 8 °C rise and 3.8 kJ released.

Lab page: proteus-vr.com/labslist/reaction-rate-and-enthalpy/

060 — Reaction rate between molecules

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.2 – Rate of reaction
NGSS (HS)	HS-PS1-5 · SEP 2, SEP 4 · CCC 2
NGSS (MS)	MS-PS1-2
Summary	Comparing a metal with its oxide



OVERVIEW

Two substances, one acid, one calorimeter, and a question a single experiment cannot answer: how much energy is released when magnesium burns in oxygen? Magnesium burns far too fiercely, and far too brightly, to be measured directly in a school calorimeter, and the reaction cannot be persuaded to happen slowly in a beaker of water. The way round the problem is the standard trick of thermochemistry — measure two reactions that can be done safely, then combine them arithmetically to reach the one that cannot. That is Hess's law: because enthalpy is a state function, the energy change between two states does not depend on the route taken between them, so a reaction that is impossible to measure can be assembled out of reactions that are easy. The two easy reactions are the ones done here. Magnesium metal dissolves in hydrochloric acid, giving hydrogen and a magnesium chloride solution; magnesium oxide dissolves in the same acid, giving the same solution and water instead of hydrogen. Both are exothermic, both go to completion in a few minutes, and both are safe in a closed vessel with dilute acid.

OBJECTIVES

- Familiarization with the calorimetry bench
- Running a repeated measurement cleanly
- Two reactions of the same metal
- Calorimetric measurement
- Comparing rates as well as energies
- Critical evaluation of the result

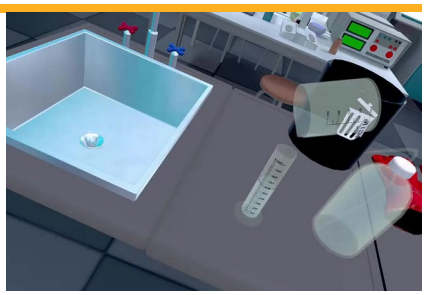
WHAT STUDENTS DO

- React magnesium ribbon — add about 0.5 g of magnesium ribbon to 100 mL of 1 M HCl in the calorimeter and start the stirrer.
- Record the thermal curve — watch the temperature in the results table until it stops rising near 140 s; expect about 22 °C and 10 kJ.
- Repeat with the oxide — rinse, then run the same protocol with 1 g of magnesium oxide; expect about 7 °C and 3 kJ near 180 s.

Lab page: proteus-vr.com/labslist/reaction-rate-between-molecules/

061 — The influence of contact surface on reaction rate 1

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.2 – Rate of reaction
NGSS (HS)	HS-PS1-5 · SEP 3, SEP 4 · CCC 2
NGSS (MS)	MS-PS1-2
Summary	Surface area and reaction rate



OVERVIEW

Grinding a solid is one of the oldest ways of making a slow reaction fast. Pharmaceutical tablets are milled to a controlled particle size so that they dissolve at a predictable rate, cement is ground to a specified fineness because that is what fixes how quickly concrete sets, and a power station burns pulverised coal in seconds where a lump of the same coal would smoulder for hours. In none of these cases has the chemistry been changed. What has changed is the amount of surface at which the reaction is allowed to happen. A reaction between a solid and a solution can only take place where the two phases meet, so its rate is proportional to the area of that interface. Dividing a fixed mass of metal into smaller pieces leaves the mass, the number of moles and the total energy available for release exactly as they were, but multiplies the area over which acid can arrive. Surface area therefore changes how fast a reaction runs without changing how far it goes or how much heat it gives out, and keeping those two ideas apart is the main intellectual work of this laboratory. In this laboratory you will run one reaction twice and change one thing about it.

OBJECTIVES

- Surface area and reaction rate
- Reading a temperature–time curve
- Separating rate from energy
- Quantitative calorimetry
- Controlled comparison and laboratory practice

WHAT STUDENTS DO

- React the powder — weigh about 0.6 g of magnesium powder into 100 mL of 1 M HCl and start the stirrer and stopwatch.
- Track the temperature — read the graph until the plateau near 84 s; expect a rise of about 25 °C, or roughly 11 kJ.
- Repeat with ribbon — run the same protocol with 0.6 g of magnesium ribbon; the plateau arrives near 140 s instead of 84 s.

Lab page: proteus-vr.com/labslist/the-influence-of-contact-surface-on-reaction-rate-1/

062 — The influence of contact surface on reaction rate 2

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.2 – Rate of reaction
NGSS (HS)	HS-PS1-5 · SEP 3, SEP 4 · CCC 2
NGSS (MS)	MS-PS1-2
Summary	Surface area, concentration and acid strength

OVERVIEW

Limestone is attacked by acid wherever the two meet, and the consequences are visible on a scale from the industrial to the geological. Flue gases are scrubbed with finely ground limestone because a powder reacts in minutes where a lump would take days; carved stonework on old buildings is eaten away by acidified rain at rates that depend on how weathered and porous the surface has become; and whole cave systems are dissolved out of limestone by groundwater carrying nothing stronger than dissolved carbon dioxide. In each case the reaction is the same one, and what differs is how fast it runs. Three things govern that rate: how much surface the solid presents, how concentrated the acid is, and how readily the acid gives up its protons. The first two act on the number of collisions per second between acid and carbonate, the third on how many of the acid molecules present are actually dissociated at any instant. All three can be separated experimentally by changing one of them at a time and timing the reaction, which is what this laboratory does. You will run four reactions of calcium carbonate with acid on a stirred hot plate and time each one to completion.

OBJECTIVES

- Contact surface and reaction rate
- Concentration and reaction rate
- Strong and weak acids
- Experimental design and measurement
- Laboratory practice

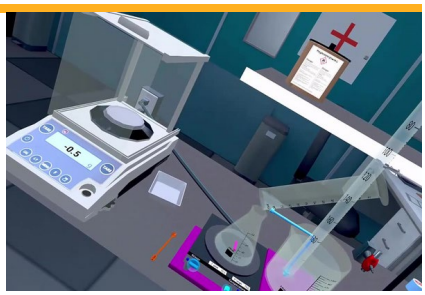
WHAT STUDENTS DO

- Compare two acids — add 2.71 g of $CaCO_3$ powder to stirred 2 M HCl and to 2 M acetic acid; expect about 50 s versus 150 s.
- Compare two forms — react the same mass of powder against a solid lump in 2 M HCl; the lump needs about 115 s versus 50 s.
- Compare concentrations — react equal powder samples in 2 M and 1 M HCl; the dilute acid takes about 105 s instead of 50 s.

Lab page: proteus-vr.com/labslist/the-influence-of-contact-surface-on-reaction-rate-2/

063 — The influence of concentration on reaction rate 1

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.2 – Rate of reaction
NGSS (HS)	HS-PS1-5 · SEP 3, SEP 4 · CCC 2
NGSS (MS)	MS-PS1-2
Summary	Concentration and rate of gas production



OVERVIEW

Collecting the gas that a reaction gives off is one of the oldest ways of following its progress, and still one of the most direct: every millilitre that appears in the burette stands for a known number of molecules, so a graduated tube and a stopwatch are enough to turn a chemical change into a curve. The same measurement is used industrially wherever a gas is the product or the by-product of a process — hydrogen generation, fermentation, the anaerobic digestion of biomass, the curing of concrete — and in the analytical laboratory it is how carbonate content and the strength of an effervescent tablet are determined. The rate of a reaction between a solid and a dissolved reagent is set at the surface where the two meet. Dissolved molecules arrive at that surface at a frequency proportional to how many of them there are per unit volume, so doubling the concentration of the acid roughly doubles the number of productive encounters each second.

OBJECTIVES

- Assembly and operation of a gas-collection apparatus
- Stoichiometry and the gas laws
- Chemical kinetics
- Quantitative measurement and graphing
- Interpretation of data
- Safety and waste handling

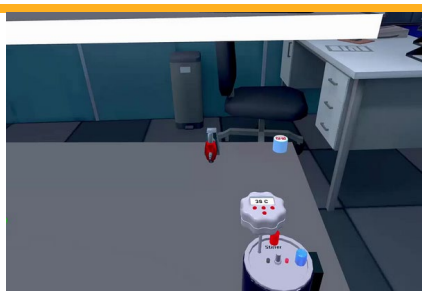
WHAT STUDENTS DO

- Build the apparatus — invert a water-filled gas burette in a 1 L beaker holding at least 800 mL of water and clamp it.
- Start the reaction — add about 0.2 g of magnesium to 150 mL of 0.3 M HCl, fit the elbow stopper, and start the stirrer.
- Measure and compare — read the burette every 10 s; expect about 204 mL of H_2, then repeat at 0.2 M and 0.5 M.

Lab page: proteus-vr.com/labslist/the-influence-of-concentration-on-reaction-rate-1/

064 — The influence of concentration on reaction rate 2

IB Programme	Chemistry — Change, Energy
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.2 – Rate of reaction
NGSS (HS)	HS-PS1-5 · SEP 3, SEP 4 · CCC 2
NGSS (MS)	MS-PS1-2
Summary	Concentration and reaction rate



OVERVIEW

A reaction that gives out heat announces its own progress. If the vessel is insulated well enough that the heat stays where it is made, the temperature of the contents rises in step with the amount of reaction that has happened, so a thermometer becomes a clock and a yardstick at once: the height of the rise says how much reacted, the steepness of it says how fast. Chemical engineers use exactly this reading to control industrial reactors, where a runaway is detected as a temperature that climbs faster than the cooling can remove it, and calorimetry of this kind is how the energy content of a fuel or a foodstuff is certified. Two separate things are being read off the same trace, and keeping them apart is the point of the laboratory. How far a reaction goes is fixed by the reagent that runs out first, and here that is always the magnesium: the same mass of metal releases the same quantity of heat, so the final temperature is the same whatever the acid.

OBJECTIVES

- Operation of a calorimeter
- Thermochemistry
- Stoichiometry and the limiting reagent
- Chemical kinetics
- Measurement and interpretation of data
- Safety and waste handling

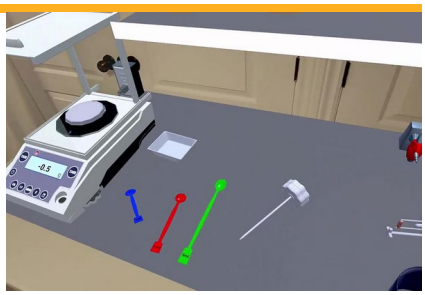
WHAT STUDENTS DO

- React with 1 M acid — weigh about 0.4 g of magnesium powder into 100 mL of 1 M HCl and start the stirrer and stopwatch.
- Record the outcome — note the plateau near 50 s; expect a rise of about 17 °C, or roughly 7.6 kJ released.
- Repeat with 2 M acid — run the identical protocol with 100 mL of 2 M HCl; the same 17 °C rise arrives in about 22 s.

Lab page: proteus-vr.com/labslist/the-influence-of-concentration-on-reaction-rate-2/

065 — Hess’s Law

IB Programme	Chemistry — Energy, change
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 1.2 – Energy cycles
NGSS (HS)	HS-PS1-4 · SEP 5, SEP 6 · CCC 5
NGSS (MS)	MS-PS1-6
Summary	Thermodynamics and enthalpy relationships



OVERVIEW

Calorimetry is how chemistry puts a number on heat. A vessel is insulated so that whatever energy a process releases or absorbs stays in its contents, the temperature of those contents is read before and after, and the energy follows from the mass, the specific heat capacity and the temperature change. Numbers obtained this way are what a process engineer uses to size a cooling jacket, what a food laboratory reports as a calorie count, and what a lime or cement plant uses to budget the fuel needed to drive carbon dioxide out of limestone. The measurement is worth making because enthalpy is a state function: the heat exchanged in going from one set of substances to another depends only on what those substances are, not on the route taken between them. That is Hess's law. It means a reaction too slow, too violent or too impure to measure directly can still be obtained, by adding the enthalpies of any sequence of steps that starts and finishes in the right place. It also means a measured heat says nothing on its own — it has to be divided by the amount of substance responsible for it, so every calorimetric result begins with a mole count and a limiting reagent.

OBJECTIVES

- Calorimetric technique
- Measuring an amount of substance
- Turning a temperature change into an enthalpy
- Telling physical heat effects from chemical ones
- Applying Hess's law
- Reading a control experiment

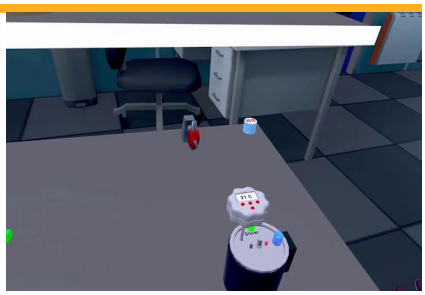
WHAT STUDENTS DO

- Mix water and ethanol — combine 100 mL of water with 100 mL of ethanol and record the rise of about 8 °C.
- Dissolve two solids — add 9.2 g of NH_4Cl to 100 mL of water (a 5-8 °C drop), then 9.5 g of insoluble $CaCO_3$ (no change).
- Run the acid reactions — react $CaCO_3$ with 100 mL of 2 M HCl (about +4 °C), then neutralize equal volumes of 1 M NaOH and HCl (+6.4 °C).

Lab page: proteus-vr.com/labslist/hesss-law/

066 — Endothermic & exothermic reactions

IB Programme	Chemistry — Energy Transfer
Secondary Programme	DP Chemistry / DP Physics
Syllabus Reference	Reactivity 1.2 – Energy cycles / B.4 Thermodynamics
NGSS (HS)	HS-PS1-4 · SEP 3, SEP 6 · CCC 5
NGSS (MS)	MS-PS1-6
Summary	Observing heat exchange in reactions



OVERVIEW

Instant hot packs and instant cold packs are the same object with a different filling. Squeeze one and a sachet bursts, a solid meets water, and within seconds the pack is either uncomfortably warm or cold enough to put on a sprain — with no heater, no refrigerant and no moving parts. The same physics decides whether a cement pour has to be cooled, whether a bag of fertiliser can be stored next to anything, and why a bath bomb feels cool as it fizzes. Every one of these is a process whose energy books do not balance at the temperature you started at, so the difference is taken from, or paid into, the surroundings. Chemists label the two directions endothermic and exothermic, and the labels refer to the system, not to the thermometer: an exothermic process releases energy, so the surroundings warm and the reading rises. The energy itself comes from bonds and from the forces between particles. Pulling an ionic lattice apart or breaking a covalent bond costs energy; hydrating the freed ions, or forming a new bond, returns it.

OBJECTIVES

- Classifying a process by sign
- Calorimetric technique
- Measuring an amount of substance
- Turning a temperature change into an energy
- Separating chemical change from physical change
- Handling corrosive reagents

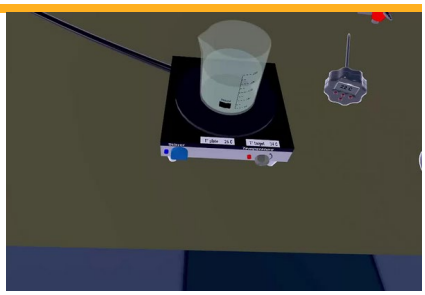
WHAT STUDENTS DO

- Dissolve sodium hydroxide — add about 4 g of NaOH to 100 mL of distilled water in the calorimeter and stir; expect about +10.6 °C.
- React acid with bicarbonate — repeat with 50 mL of 1 M citric acid and about 4.5 g of sodium bicarbonate; expect a 4.7 °C drop.
- Classify and calculate — read the maximum and minimum temperatures from the results table and compute the energy change per mole.

Lab page: proteus-vr.com/labslist/endothermy-exothermy/

067 — Specific heat capacity

IB Programme	Physics — Energy, transformation
Secondary Programme	DP Physics
Syllabus Reference	B.4 Thermodynamics
NGSS (HS)	HS-PS3-4 · SEP 5 · CCC 5, CCC 7
NGSS (MS)	MS-PS3-3; MS-PS3-4
Summary	Heat transfer investigation



OVERVIEW

Every substance charges a different price for a degree of temperature. Pour equal volumes of water and cooking oil into identical pans on identical burners and the oil is smoking while the water is still merely warm; the sea in September is warmer than the land beside it although both have had the same sunshine. The quantity behind all of this is specific heat capacity, the energy needed to raise one gram of a substance by one degree, and it is one of the most consequential numbers in engineering. It decides what a car radiator is filled with, how much concrete a thermal store needs, why coastal winters are mild, and why water is the coolant of choice almost everywhere it can be used. The way to measure it is to let two things at different temperatures come to equilibrium and see where the common temperature lands. Energy is conserved, so whatever the hot substance gives up the cold one takes: m 1 c 1 (T f − T 1) + m 2 c 2 (T f − T 2) = 0. Rearranged, that says the final temperature is the average of the two starting temperatures weighted by each substance's heat capacity — so the equilibrium point sits closer to whichever substance has more capacity to hold heat.

OBJECTIVES

- The energy balance as a working tool
- Specific and molar heat capacity
- Calorimetric technique
- Using a control experiment
- Separating two effects that push the same way
- Handling a volatile flammable liquid and hot water

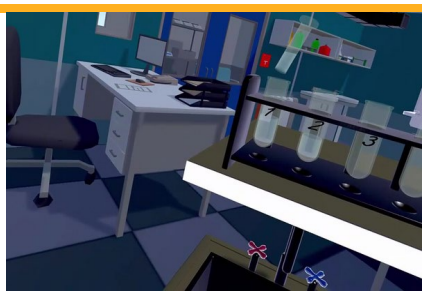
WHAT STUDENTS DO

- Set up the water trial — pour 50 mL of distilled water into the calorimeter and heat a beaker of tap water on the hot plate.
- Mix and record — add 50 mL of the hot water, close the lid, run the stirrer, and read the equilibrium temperature near 50 °C.
- Repeat with ethanol — replace the cold water with 50 mL of ethanol, mix with hot water again, and expect about 70 °C.

Lab page: proteus-vr.com/labslist/067-specific-heat-capacity/

070 — The qualitative aspect of chemical equilibrium

IB Programme	Chemistry — Equilibrium systems
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 2.3 – Extent of reaction
NGSS (HS)	HS-PS1-6 · SEP 2, SEP 6 · CCC 7
NGSS (MS)	—
Summary	Solubility equilibrium and Le Châtelier's principle



OVERVIEW

Solubility equilibrium is the reason a salt can be called “insoluble” and still be present in solution. Calcium sulfate is the standard industrial example: it is the scale that forms in boilers, cooling towers, desalination plants and oil-well tubing, it is the gypsum of plaster and drywall, and it is what sets the sulfate content of well water. Water-treatment chemists decide where it will deposit and where it will redissolve from a single number, its solubility product. When a sparingly soluble salt sits in contact with a solution of its own ions, two processes run at the same time: ions leave the surface of the solid, and ions in the liquid return to it. Equilibrium is reached when the two rates become equal, not when either one stops. For calcium sulfate the condition is [Ca 2+][SO 4 2−] = K sp = 4.9 × 10 −5 at 25 °C. A solution whose ion product exceeds that value deposits solid until it no longer does; a solution below it dissolves solid until it reaches it. Adding more of either ion therefore does not change K sp — it moves the position of the equilibrium, and the surplus appears as solid. In this laboratory you will approach the same equilibrium from both sides.

OBJECTIVES

- Chemical equilibrium as a dynamic state
- Solubility equilibria and the solubility product
- Le Châtelier’s principle and the common-ion effect
- Complete versus incomplete reactions
- Qualitative analysis and the logic of a spot test
- Laboratory technique

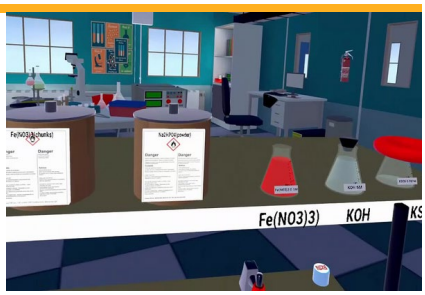
WHAT STUDENTS DO

- Prepare the salt solution — dissolve about 4.3 g of sodium chloride in 50 mL of distilled water in the 100 mL beaker; all three starting solutions are colorless.
- Run the forward reaction — mix 10 mL of 0.10 M $CaCl_2$ with 10 mL of 0.10 M Na_2SO_4 in two test tubes, then add 10 mL more of one reagent to each.
- Test the dissolution equilibrium — stir 3 g of solid $CaSO_4$ into the brine, then add either reagent to 10 mL portions of the clear supernatant.

Lab page: proteus-vr.com/labslist/the-qualitative-aspect-of-chemical-equilibrium/

071 — Le Chatelier’s Principle

IB Programme	Chemistry — Energy & Systems
Secondary Programme	DP Chemistry
Syllabus Reference	Reactivity 3.2 – Electron transfer reactions
NGSS (HS)	HS-PS1-6 · SEP 3, SEP 7 · CCC 2, CCC 7
NGSS (MS)	—
Summary	Le Chatelier's Principle and equilibrium shifts



OVERVIEW

Le Châtelier’s principle is the rule that lets a chemical engineer squeeze more product out of a reaction that refuses to go to completion. It is why ammonia is synthesised under pressure, why a blast furnace is run with excess carbon monoxide, and why the oxygen your blood picks up in the lungs is released again in working muscle. The system used to teach it in almost every laboratory in the world is the one on this bench: iron(III) and thiocyanate, which combine to give a complex so intensely coloured that a change in concentration can be read off by eye, with no instrument at all. The reaction is Fe 3+ (aq) + SCN − (aq) ⇌ [FeSCN] 2+ (aq), and the deep blood-red belongs entirely to the complex on the right; both reactants are almost colourless at these concentrations. At equilibrium the concentrations satisfy K f = [FeSCN 2+] / ([Fe 3+][SCN −]) ≈ 1.4 × 10 2 at 25 °C. Disturb the mixture — add one of the reactants, take one away, warm it or cool it — and the reaction quotient Q no longer equals K f ; the system responds by consuming or releasing the complex until it does.

OBJECTIVES

- Le Châtelier’s principle, stated and applied
- Complexation equilibria and colour as a measure
- Adding a species, and removing one
- Temperature as a stress
- Controlled qualitative comparison
- Technique and safety

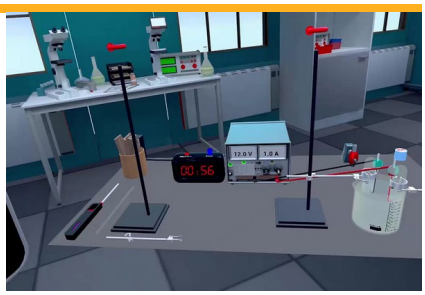
WHAT STUDENTS DO

- Prepare the mixture — add 10-12 drops of 0.1 M $Fe(NO_3)_3$ to 50 mL of 0.001 M KSCN, stir, and divide into eight tubes of about 6 mL.
- Shift by concentration — add 1.5-2 g of KSCN to tube 2, $Fe(NO_3)_3$ to tube 3 and both reagents to tube 4, then shake each tube.
- Remove ions and vary heat — add KOH to tube 5 and Na_2HPO_4 to tube 6, cool tube 7 in ice and hold tube 8 at 80 °C.

Lab page: proteus-vr.com/labslist/le-chateliers-principle/

072 — Water electrolysis

IB Programme	Chemistry — Transformation of Energy
Secondary Programme	DP Chemistry / DP Physics
Syllabus Reference	Reactivity 3.2 – Electron transfer / D.2 Electric fields
NGSS (HS)	HS-PS1-2; HS-PS3-1 · SEP 3, SEP 6 · CCC 5
NGSS (MS)	MS-PS1-2
Summary	Decomposition of water into hydrogen and oxygen



OVERVIEW

Electrolysis is how industry makes the substances that cannot be dug out of the ground. Aluminium is won from its oxide in an electrolytic cell, chlorine and sodium hydroxide are made by electrolysing brine, and every chromed or galvanised surface is an electrode that was once part of a circuit. The version in this laboratory — splitting water into hydrogen and oxygen — is also the one with the largest future: it is the route by which surplus electricity from wind and solar generation is stored as hydrogen, and it is the same reaction a fuel cell runs backwards to release that energy again. Water is stable, and that is the difficulty. Its free energy of formation is −237 kJ per mole, so pulling it apart costs at least that much work, supplied here as electrical energy. A cell does it by splitting the job between two electrodes: at the negative one, hydrogen ions accept electrons and leave as hydrogen gas; at the positive one, water molecules give up electrons and leave as oxygen. Two conditions have to be met for anything to happen. The solution must conduct, which pure water barely does, so an electrolyte is added; and the applied voltage must exceed the thermodynamic minimum of 1.23 V.

OBJECTIVES

- The principle of electrolysis
- Oxidation and reduction at named electrodes
- Stoichiometry made visible
- The choice of electrolyte
- Identifying the products
- Assembly and safety

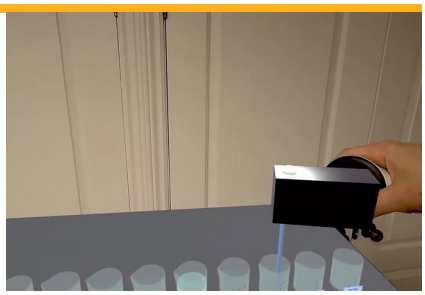
WHAT STUDENTS DO

- Set up the cell — clamp two water-filled test tubes upside down in a 1 L beaker of tap water and attach the red and black electrodes.
- Run the electrolysis — add 15 mL of 1.0 M sulfuric acid, stir with the glass rod and pass current for about one minute while gas collects.
- Test the products — insert a glowing ember and then a lit splint into each tube; the gas from the negative electrode gives a sharp pop.

Lab page: proteus-vr.com/labslist/water-electrolysis/

073 — Conductivity

IB Programme	Physics — Energy & Systems
Secondary Programme	DP Chemistry / DP Physics
Syllabus Reference	Structure 2.4 – Bonding and materials / B.5 Circuits
NGSS (HS)	HS-PS1-2; HS-PS3-3 · SEP 4 · CCC 2
NGSS (MS)	MS-PS1-2
Summary	Conductivity of solutions and electrolytes



OVERVIEW

Electrical conductivity is the fastest measurement made in any water laboratory. A drinking-water plant, a dialysis unit, a hydroponic greenhouse and a boiler feedwater line all monitor it continuously, because a single number tells an operator how much dissolved ionic material a liquid is carrying, in real time and without destroying the sample. The same measurement is what a soil probe reports as salinity, what a swimming-pool controller uses to decide how much salt to add, and what a clinical laboratory uses to check that a saline bag is what its label says. A liquid conducts an electric current only if it contains charged particles that are free to move through it. Water itself contains almost none, so pure water is a poor conductor; what matters is whether the dissolved substance releases ions into the solution. An ionic solid such as sodium chloride is already built of ions and only needs its lattice pulled apart by hydration. A polar molecule such as hydrogen chloride contains no ions at all until water takes a proton from it, and how far that proton transfer goes is set by the acid constant. A molecule such as sucrose has neither a lattice to break nor a proton to give: it dissolves beautifully and releases nothing.

OBJECTIVES

- Distinguishing electrolytes from non-electrolytes
- Bonding as the cause of conduction
- Operating the conductivity detector
- Quantitative treatment of conductivity
- Connecting the measurement to its uses

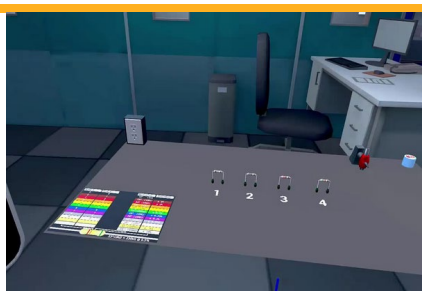
WHAT STUDENTS DO

- Prepare the samples — set out the labeled 50 mL beakers of solutions and fill two more with 50 mL of distilled water and tap water.
- Measure conductivity — rinse the electrodes with distilled water and dry them between samples, then score the bulb as 0, 1 or 2.
- Classify the results — expected: NaOH, NaCl, HCl, $Ca(OH)_2$ and KOH score 2; CH_3COOH, oxalic acid and tap water score 1; the rest 0.

Lab page: proteus-vr.com/labslist/conductivity/

074 — Reading a resistor

IB Programme	Physics — Energy systems
Secondary Programme	DP Physics
Syllabus Reference	B.5 Circuits
NGSS (HS)	HS-PS3-3 · SEP 8 · CCC 6
NGSS (MS)	MS-PS3-3
Summary	Resistor color code and tolerance



OVERVIEW

A resistor is the most numerous component in electronics: a mobile phone contains several hundred of them, and every one has to be the right value. The value is not printed as a number, because the parts are too small and too cheap for that. It is printed as a ring of coloured bands, a code introduced in the 1920s that is still used on through-hole resistors today, is readable from any angle, survives heat and solvents, and needs no magnifier. Being able to read it is the first practical skill of an electronics bench, and being able to check it with a meter is the second. The quantity the bands encode is defined by Ohm's law, R = V / I: a resistance of one ohm passes one ampere when one volt is placed across it. On a four-band resistor the first two bands give the two significant figures of that number, the third gives the power of ten to multiply them by, and the fourth states the tolerance — the manufacturer's promise about how far the real part may stray from its nominal value. That fourth band is the interesting one, because it is an admission: resistors are made in bulk from a resistive film whose thickness cannot be controlled perfectly, so a part is sold not as a value but as a range.

OBJECTIVES

- Reading the four-band colour code
- Tolerance and the range of acceptable values
- Using an ohmmeter
- Recognising the limits of the instrument
- Preferred values and component selection

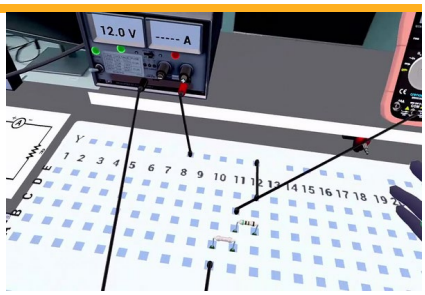
WHAT STUDENTS DO

- Read the bands — use the color chart: the first two bands give a number, the third the multiplier, the fourth the tolerance.
- Calculate the range — record the nominal value and tolerance, then compute the minimum and maximum acceptable resistance for each resistor.
- Measure and compare — measure each resistor with the ohmmeter and check it against its range; the answers are 0.15 Ω, 180 Ω, 22 Ω and 5.3 Ω.

Lab page: proteus-vr.com/labslist/reading-a-resistor/

075 — Electrical circuit assembly

IB Programme	Physics — Energy systems
Secondary Programme	DP Physics
Syllabus Reference	B.5 Current and circuits
NGSS (HS)	HS-PS3-3 · SEP 2, SEP 3 · CCC 4
NGSS (MS)	MS-PS3-3
Summary	Series circuit building



OVERVIEW

Every piece of electronics ever built starts as a loop: a source, a conductor and something that limits the current. A breadboard is the standard way to make that loop temporarily, without soldering, so that a design can be tried, measured and changed in minutes. It is the tool every electronics laboratory, prototyping bench and undergraduate course begins with, and the reason a modern product can go from a sketch to a working circuit in an afternoon. Two rules govern everything measured on such a loop. Ohm's law, V = IR, relates the current through a component to the voltage across it. Kirchhoff's loop rule states that the voltages around any closed loop must sum to zero — energy given to each charge by the supply is entirely given back to the components it passes through. Together they have a useful consequence: in a single loop the current is the same everywhere, so components in series divide the supply voltage between them in proportion to their resistances. That is enough to find the value of a component you cannot read, using nothing but a voltmeter and one resistor whose value you do know.

OBJECTIVES

- Understanding the components and the breadboard
- Building a series circuit
- Measuring with a multimeter
- Applying Ohm's law and Kirchhoff's loop rule
- Judging the quality of a result
- Recording work

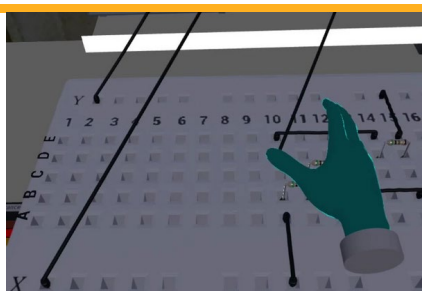
WHAT STUDENTS DO

- Wire the breadboard — connect the supply to rows X and Y, place the mystery resistor at B-10 to B-11 and a known resistor at C-11 to C-12.
- Measure the voltage — connect the multimeter leads to the COM and VHz jacks, set the dial to V and probe slots D-11 and D-12.
- Calculate and submit — compute the current with I = V/R, find the mystery resistor's voltage drop and resistance, then send the saved diagram and data.

Lab page: proteus-vr.com/labslist/electrical-circuit-assembly/

076 — Assembling an electrical circuit in parallel

IB Programme	Physics — Systems
Secondary Programme	DP Physics
Syllabus Reference	B.5 Current and circuits
NGSS (HS)	HS-PS3-3 · SEP 2, SEP 3 · CCC 4
NGSS (MS)	MS-PS3-3
Summary	Parallel circuit analysis



OVERVIEW

Almost every electrical installation outside a string of fairy lights is wired in parallel. The lamps in a classroom, the outlets along a wall, the panels of a solar array and the cells of a battery pack are all connected across the same two supply rails, so that each one receives the full supply voltage and can be switched on or off without disturbing the others. The alternative — wiring devices one after another in a single loop, as in laboratory 075 — makes every device depend on all the others, which is why one failed bulb used to darken a whole string. The physics of the arrangement rests on two statements. Because every branch is connected between the same pair of points, every branch carries the same voltage. And because charge cannot accumulate at a junction, the currents drawn by the branches must add up to the current delivered by the source; that is Kirchhoff's first law. Its consequence is that resistances in parallel do not add — their reciprocals do — so a parallel combination always conducts better than any one of its branches, and adding a branch to a circuit increases the current the supply must provide.

OBJECTIVES

- Building a circuit on a breadboard
- Telling a branch from a component
- Operating the multimeter
- Applying Kirchhoff's first law
- Applying Ohm's law and the parallel rule
- Judging the measurement itself
- Recording and reporting

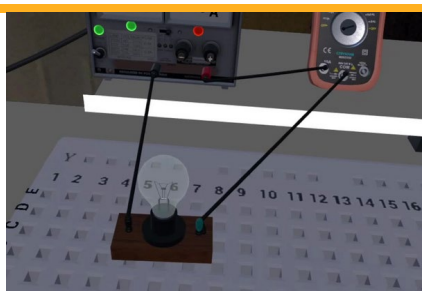
WHAT STUDENTS DO

- Build the first branch — wire the supply to rows X and Y, then add resistors at B-10 to B-11 and C-11 to C-12 with connecting wires.
- Add a second branch — place a switch wired from E-10 and E-14, add a third resistor at D-14 to D-15, then save the circuit.
- Measure and deduce — replace the switch with the multimeter in A mode, read the branch and source currents, then apply Kirchhoff's first law.

Lab page: proteus-vr.com/labslist/parallel-electrical-circuit-assembly/

077 — Impact of current on the brightness of a lamp

IB Programme	Physics — Energy transfer
Secondary Programme	DP Physics
Syllabus Reference	B.5 Circuits
NGSS (HS)	HS-PS3-3 · SEP 4 · CCC 2, CCC 5
NGSS (MS)	MS-PS3-3
Summary	Current–light intensity relationships



OVERVIEW

A filament lamp is the simplest instrument in a laboratory that turns an electrical quantity into something the eye can read directly. Dimmer switches, the fading headlights of a car whose battery is going flat, and the brightness control on an instrument panel all work on the same principle: change the current through the filament and its temperature, and therefore its light, changes with it. The relationship is worth pinning down because it is not the one most people expect — light does not fall off in step with current, it falls off very much faster. The reason is that the filament is heated by the power delivered to it, and power is not proportional to current but to its square, P = I 2 R. In a series circuit there is only one path, so the same current passes through every component; adding a resistor raises the total resistance, and by Ohm's law I = V/R the current everywhere falls. The lamp then receives a smaller current and, at the same time, a smaller share of the supply voltage, and the two effects multiply. A further step of the same kind links power to what is actually seen, because a cooler filament radiates less and radiates a smaller fraction of what it does emit as visible light.

OBJECTIVES

- Assembling and modifying a series circuit
- Measuring current
- Applying Ohm's law
- Relating power to brightness
- Identifying a relationship from data
- Judging the limits of a qualitative observation

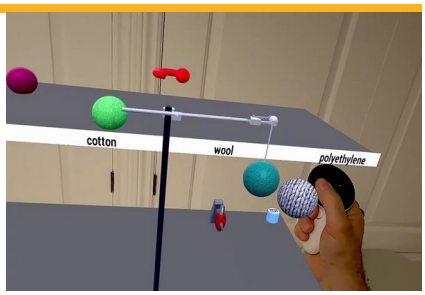
WHAT STUDENTS DO

- Build the base circuit — assemble a series circuit with only a lamp or LED, switch on the supply and confirm that it illuminates.
- Measure and describe — read the current on the multimeter, record a qualitative brightness rating and save the circuit.
- Add resistance twice — repeat the measurement with one resistor added, then with a second, and compare the three current-brightness pairs.

Lab page: proteus-vr.com/labslist/impact-of-current-on-the-brightness-of-a-lamp/

078 — Static electricity

IB Programme	Physics — Forces
Secondary Programme	DP Physics
Syllabus Reference	D.2 Electric fields
NGSS (HS)	HS-PS2-4 · SEP 2, SEP 3 · CCC 2
NGSS (MS)	MS-PS2-3
Summary	Electrostatics and charge transfer



OVERVIEW

Static electricity is the oldest branch of the subject and still the one people meet first: a jumper crackling as it comes off, a door handle that stings after a walk across a carpet, hair standing away from a comb, cling film that will not let go of itself. Industrially the same effect has to be managed rather than admired — it is why fuel tankers are bonded to earth before filling, why electronic components ship in conductive bags, and it is also put to work deliberately in photocopiers, laser printers, electrostatic paint spraying and the precipitators that clean flue gases. The physics behind all of it is one sentence long: when two different insulating materials are brought into intimate contact and separated, electrons move from one surface to the other, leaving one object with a net negative charge and the other with an equal positive charge. Which way the electrons go depends only on the pair of materials, and the materials can be ranked in a list — the triboelectric or electrostatic series — in which whichever member sits higher gives up electrons and becomes positive. Once charged, the objects obey Coulomb's law: like charges repel, opposite charges attract, and the force falls off as the square of the separation.

OBJECTIVES

- Charging an object and knowing that you have
- Reading attraction and repulsion correctly
- Using the electrostatic series
- Applying Coulomb's law
- Observing and documenting systematically

WHAT STUDENTS DO

- Suspend and charge — hang a polyethylene ball from a movable rod on each stand, then charge both by rubbing them with the wool ball.
- Test polyethylene — bring one charged ball close to the other without contact and record the repulsion, then note the attraction to the wool.
- Repeat with acetate — charge acetate balls with the cotton ball: two acetate balls repel, and charged acetate attracts charged polyethylene.

Lab page: proteus-vr.com/labslist/static-electricity/

079 — Magnetic fields

IB Programme	Physics — Forces
Secondary Programme	DP Physics
Syllabus Reference	D.2 Magnetic fields
NGSS (HS)	HS-PS2-5 · SEP 2, SEP 3 · CCC 2, CCC 6
NGSS (MS)	MS-PS2-3; MS-PS2-5
Summary	Magnetic field mapping and compass use

OVERVIEW

A magnet's influence extends into the space around it, and that space can be mapped. Every compass needle that has ever pointed north has been reading such a map, drawn in this case by the Earth itself, whose molten iron core makes the planet one enormous and slightly crooked bar magnet. The same mapping underlies the read head of a hard disc, the loudspeaker in a telephone, the deflection of charged particles in a medical scanner, and the magnetic clasp on a bag. What makes the field hard to teach is that it is invisible — and what makes this laboratory work is that iron filings and a compass, between them, make it visible. A magnetic field has a direction at every point, and the convention is to draw lines whose tangent gives that direction and whose crowding indicates the strength. Outside a magnet the lines run from the north pole to the south pole; inside the magnet they continue from south to north, so that every line closes on itself. There are no loose ends, because there is no such thing as an isolated magnetic pole: break a bar magnet in half and you get two smaller bar magnets, never a north on its own. Two lines can never cross, because the field cannot have two directions at the same place.

OBJECTIVES

- Reading a field map
- Using the compass as an instrument
- Combining two fields
- Distinguishing poles
- Recording and comparing

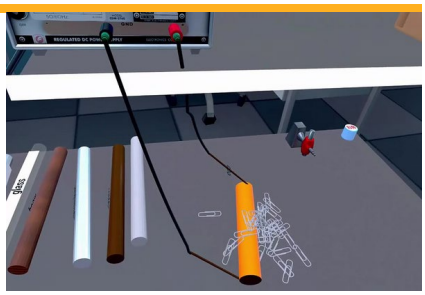
WHAT STUDENTS DO

- Set up assembly A — place a straight bar magnet on the iron filings sheet, poles oriented as shown, and observe the pattern that forms.
- Photograph each position — place the compass at each of the four marked positions and save an image of the setup after every move.
- Repeat for B, C, D — rebuild with two magnets; like poles facing make the field lines curve apart, while assembly D links the nearest opposite poles.

Lab page: proteus-vr.com/labslist/magnetic-fields/

080 — Solenoids

IB Programme	Physics — Systems & Energy
Secondary Programme	DP Physics
Syllabus Reference	D.4 – Induction
NGSS (HS)	HS-PS2-5; HS-PS3-5 · SEP 2, SEP 3 · CCC 4, CCC 6
NGSS (MS)	MS-PS2-3
Summary	Magnetic field and current relationship



OVERVIEW

A solenoid is a coil of wire that becomes a magnet when current flows through it, and stops being one the instant the current stops. That single property — a magnet with a switch — is what makes electromagnetism useful. It is how a scrapyard crane picks up a car and drops it, how the starter of an engine throws its pinion forward, how a door lock releases when a card is presented, how a loudspeaker cone is driven, how a relay lets a small current control a large one, and, wound from superconducting wire and cooled with liquid helium, how the several-tesla field of a magnetic resonance scanner is produced. The field inside a long coil is uniform and points along the axis, and its strength is B = μ 0 nI, where n is the number of turns per metre and I the current. Three things can therefore be changed to make the coil stronger: more turns in the same length, more current, or a core that is itself magnetisable. The third is the largest lever of the three. A ferromagnetic core placed inside the coil is magnetised by the coil's own field and adds its own contribution to it, which is why an iron-cored electromagnet can be hundreds of times stronger than the same coil wound around nothing at all. In this laboratory you will test each of the three factors in turn while holding the other two fixed.

OBJECTIVES

- Understanding what makes an electromagnet
- Controlling variables
- Distinguishing magnetic materials
- Using an indirect measurement
- Handling the apparatus

WHAT STUDENTS DO

- Part A: core material — run the 600-turn solenoid at 15 V with each of the six cores and with no core, recording the percentage of the load attracted.
- Part B: current — keep the soft-iron core and 600-turn coil while lowering the supply from 30 V to 15 V and then 7 V, giving about 100 %, 40 % and 20 %.
- Part C: coil density — repeat at 15 V with the 15-turn and 300-turn solenoids; the 300-turn coil reaches about 20 % of the load against 100 % for 600 turns.

Lab page: proteus-vr.com/labslist/solenoids/

081 — Energy efficiency

IB Programme	Physics — Energy Transfer
Secondary Programme	DP Physics
Syllabus Reference	A.3 – Work, energy, power
NGSS (HS)	HS-PS3-3 · SEP 4, SEP 6 · CCC 5
NGSS (MS)	MS-PS3-3
Summary	Energy conservation and losses

OVERVIEW

Every device that converts energy from one form to another wastes part of it, and the fraction that reaches its intended destination is what engineers call the efficiency of the device. It is the number printed on the energy label of a refrigerator, the figure quoted for a power station or an electric motor, and the quantity an energy audit of a building is trying to establish. Measuring it always comes down to the same two steps: count the energy going in, then count the energy arriving where it was wanted, and take the ratio. The instrument used to count the energy that arrives as heat is the calorimeter — an insulated vessel of water fitted with a heater, a stirrer and a thermometer. Electrical energy delivered to the heater is known exactly from the supply voltage, the current and the running time, because E = U I Δt. The heat that ends up in the water is known from its mass, its specific heat capacity and its temperature rise, because Q = m c ΔT. The ratio of the second to the first is the efficiency. Water is used because its specific heat capacity is large, accurately known and almost constant over a small temperature range, so the thermometer becomes a reliable energy meter.

OBJECTIVES

- Familiarization with the laboratory environment
- Safe handling of electrical apparatus
- Building and instrumenting a circuit
- Quantitative measurement of energy
- Calculating and interpreting an efficiency
- Critical evaluation of a measurement

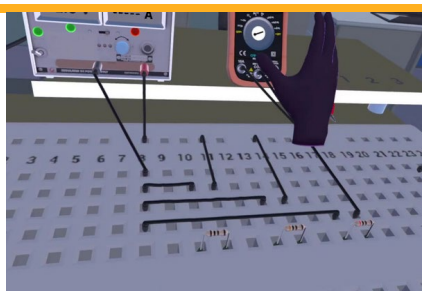
WHAT STUDENTS DO

- Set up and measure current — set the supply to 4 V, insert the multimeter in series in A mode, and read about 3.6 A.
- Heat and record — pour 200 mL of distilled water into the calorimeter, start the stirrer, and record the rise from 21.7 °C to 26.1 °C.
- Calculate efficiency — over 330 s find E ≈ 4752 J and Q ≈ 3678 J, an efficiency near 77 %; discuss the shortfall.

Lab page: proteus-vr.com/labslist/081-energy-efficiency/

110 — Kirchhoff law

IB Programme	Physics — Systems
Secondary Programme	DP Physics
Syllabus Reference	B.5 – Current and circuits
NGSS (HS)	HS-PS3-3 · SEP 5, SEP 6 · CCC 4, CCC 5
NGSS (MS)	MS-PS3-3
Summary	Electric circuit current and voltage distribution



OVERVIEW

Every electrical and electronic device, from a phone charger to a national grid, is designed and diagnosed with two rules formulated by Gustav Kirchhoff in 1845. They are not new forces of nature but two conservation laws written in circuit language. Kirchhoff's current law says that the current flowing into any junction equals the current flowing out — electric charge is conserved, so it cannot pile up at a node or vanish from one. Kirchhoff's voltage law says that around any closed loop the voltage rises and drops sum to zero — energy is conserved, so a charge carried once around a loop returns with the energy it started with. Together with Ohm's law they are sufficient to solve any resistor network, which is why they are the first tools of every electronics course. In this laboratory, you will put both laws to a direct experimental test. You will build a series circuit and then a parallel circuit from the same three resistors (100 Ω, 200 Ω and 300 Ω) on a 12 V supply, measure the current at every point and the voltage across every component with a multimeter, and verify that the currents at each junction and the voltages around each loop add up exactly as the two laws demand.

OBJECTIVES

- Understanding Kirchhoff's laws
- Circuit assembly
- Use of the multimeter
- Connecting theory to practice
- Analytical thinking

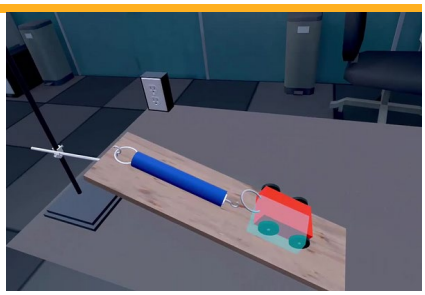
WHAT STUDENTS DO

- Build the series circuit — connect the three resistors in series on the breadboard and set the power supply to 12 V.
- Take the readings — measure the current after each resistor and at the source, then every voltage drop and the source voltage.
- Repeat in parallel — save the circuit diagram, rebuild the three resistors in parallel, and repeat all measurements.

Lab page: proteus-vr.com/labslist/110-kirchhoff-law/

082 — Effective force

IB Programme	Physics — Forces
Secondary Programme	DP Physics
Syllabus Reference	A.2 Forces and momentum
NGSS (HS)	HS-PS2-1 · SEP 4, SEP 5 · CCC 2
NGSS (MS)	MS-PS2-2
Summary	Newton's second law verification



OVERVIEW

An inclined plane is the oldest of the simple machines and still one of the most useful: it is why a wheelchair ramp exists, why a mountain road switches back instead of climbing straight up, and why a loading dock has a slope rather than a step. In every case the ramp does not reduce the work required to raise a load — it reduces the force required, by spreading that work over a longer path. Knowing how much force a given slope demands is what allows a ramp to be designed, a winch to be sized or a hillside road to be given a safe gradient. The physics is a decomposition of a single vector. Gravity pulls the cart straight down with its full weight F g = m g, but the board can only be left along its surface or pressed into perpendicular to it. Resolving the weight along those two directions gives a component parallel to the slope, F eff = F g sin θ, which is the part that tends to make the cart run down, and a component perpendicular to it, N = F g cos θ, which the board simply supports. Only the parallel component — the effective force — has to be held back, and because sin θ grows from zero at the horizontal to one at the vertical, the same cart demands a different restraint on every slope. In this laboratory you will measure that component directly.

OBJECTIVES

- Familiarization with the laboratory environment
- Correct use of a dynamometer
- Resolving a force into components
- Predicting and testing a quantitative relationship
- Comparing measurement with theory

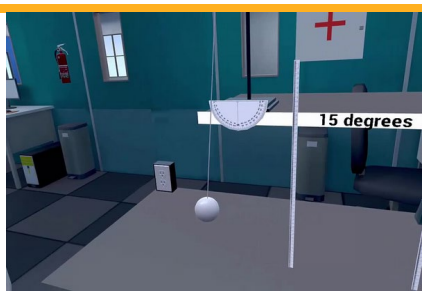
WHAT STUDENTS DO

- Set up the incline — clamp the board to the universal stand at about 20°, check the angle with the protractor, and record it.
- Measure the force — attach the cart to the dynamometer hook, keep the dynamometer parallel to the board, and read the effective force.
- Repeat and calculate — repeat at about 40° and 60°, then compute Fg = m·g and Feff = Fg·sin θ for each angle.

Lab page: proteus-vr.com/labslist/effective-force-on-an-inclined-plane/

083 — The mechanical energy of a moving object

IB Programme	Physics — Energy
Secondary Programme	DP Physics
Syllabus Reference	A.3 Work, energy, power
NGSS (HS)	HS-PS3-1; HS-PS3-2 · SEP 4, SEP 5 · CCC 5
NGSS (MS)	MS-PS3-1; MS-PS3-5
Summary	Kinetic and potential energy transfer



OVERVIEW

A swinging pendulum is the clearest demonstration in physics that energy can change form without changing amount. It is also, historically, one of the most consequential: the constancy of a pendulum's swing gave the world its first accurate clocks, held that role for nearly three centuries, and is still used to measure local gravity precisely enough to map the density of rock beneath a survey site. The same principle governs a child on a swing, a wrecking ball, a skateboard in a half-pipe and the suspended damper that steadies a tall building in the wind. The mechanical energy of an object is the sum of its gravitational potential energy, $E_p = m g h$, and its kinetic energy, $E_k = \frac{1}{2} m v^2$. When no friction acts, that sum is conserved: whatever one form loses, the other gains, instant for instant. A pendulum makes the exchange visible because it separates the two forms in space. At the ends of the swing the mass is momentarily at rest at its highest point, so the energy is entirely potential; at the bottom of the arc the mass is at its lowest point and moving fastest, so the energy is entirely kinetic. Every position in between holds a mixture whose total is always the same.

OBJECTIVES

- Familiarization with the laboratory environment
- Careful measurement of length, angle and time
- Calculating gravitational potential energy
- Applying the conservation of mechanical energy
- Relating the release angle to the energy
- Checking the model

WHAT STUDENTS DO

- Build the pendulum — clamp a rigid rod high on the universal stand, add the protractor and two 50 cm rulers, then hang a 50 g mass.
- Release and measure — set the pendulum 15° from vertical, record its height above the table, and time five full oscillations.
- Repeat and calculate — repeat at 30°; expect $E_p \approx 0.013$ J and $v \approx 0.71$ m/s at 15°, and 0.049 J and 1.4 m/s at 30°.

Lab page: proteus-vr.com/labslist/the-mechanical-energy-of-a-moving-object/

084 — Constant acceleration

IB Programme	Physics — Motion
Secondary Programme	DP Physics
Syllabus Reference	A.1 Kinematics
NGSS (HS)	HS-PS2-1 · SEP 4, SEP 5 · CCC 1
NGSS (MS)	MS-PS2-2
Summary	Acceleration and motion graphing

OVERVIEW

A cart released at the top of a ramp speeds up as it descends, and it does so at a rate that stays the same from the top of the board to the bottom. That is uniformly accelerated motion — the same amount of speed gained in every second — and it is the simplest case in which velocity changes. Engineers meet it wherever a load runs down a slope: gravity roller conveyors in a warehouse, a luge track, the ramp used to unload a truck. It is also the reference case against which every more complicated motion is compared. The cause is that only part of the cart's weight acts along the board. Gravity pulls straight down with a force mg ; on a slope of angle θ the component along the surface is mg sin θ, and the component pressing the cart into the board is mg cos θ. The first drives the cart, the second sets how hard friction resists it, so the acceleration down the slope is a = g (sin θ − μ cos θ). The mass cancels out of that expression entirely: a heavy cart and a light one accelerate identically down the same ramp, although the heavy one carries more energy when it gets there.

OBJECTIVES

- Building and characterising an inclined plane
- Recording motion with a spark timer
- Measuring velocity and acceleration from data
- Applying the equations of uniformly accelerated motion
- Resolving forces on a slope
- Accounting for the energy
- Judging the quality of a measurement

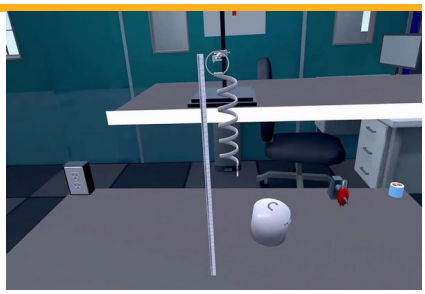
WHAT STUDENTS DO

- Set up the ramp — assemble the two boards on the stand and clamp, note the incline angle, and position the spark timer.
- Record the descent — attach the tape to the 250 g cart, start the spark timer, and release the cart down the ramp.
- Analyze the data — repeat at two steeper angles, then find the acceleration (about 0.45 m/s^2 at 15°) and the friction force.

Lab page: proteus-vr.com/labslist/084-constant-acceleration/

085 — The relationship between the deformation of a spring and the restoring force it exerts

IB Programme	Physics — Forces
Secondary Programme	DP Physics
Syllabus Reference	A.4 Rigid body mechanics
NGSS (HS)	HS-PS2-1 · SEP 4, SEP 5 · CCC 1, CCC 2
NGSS (MS)	MS-PS2-2
Summary	Hooke's Law demonstration



OVERVIEW

Springs are among the most useful mechanical components ever devised: they suspend vehicles, close doors, keep watches running and return retractable pens. The instrument a laboratory uses to measure force — the newton meter, or dynamometer — is itself nothing more than a calibrated spring, so understanding how a spring responds to a load is understanding how force itself is measured. The response is described by Hooke's law: within its elastic range, a spring exerts a restoring force proportional to its elongation, $F = k\Delta l$, where the spring constant k measures the stiffness of that particular spring. The proportionality is the point — doubling the load doubles the stretch — and it is what makes a spring usable as a measuring device. In this laboratory, you will suspend a spring from a stand, load it with weights from 1 N to 9 N in equal steps, and read the elongation produced by each load against a fixed ruler.

OBJECTIVES

- Familiarization with the laboratory environment
- Use of measuring instruments
- Understanding Hooke's law
- Graphical and mathematical analysis
- Critical analysis of results

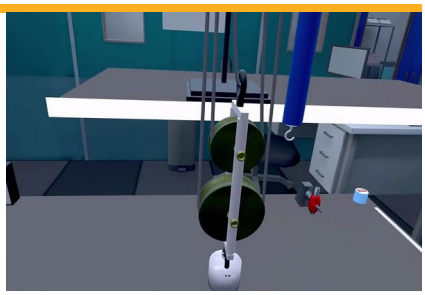
WHAT STUDENTS DO

- Mount the spring — clamp the spring to the universal stand, secure the ruler beside it, and measure the unloaded position.
- Load in steps — suspend a 1 N weight, wait until oscillation stops, and measure the new distance from the table.
- Repeat and plot — repeat up to 9 N and plot force against elongation; a 2 cm stretch per newton gives k = 0.5 N/cm.

Lab page: proteus-vr.com/labslist/085-the-relationship-between-the-deformation-of-a-spring-and-the-restoring-force-it-exerts/

086 — The operation of a hoist

IB Programme	Physics — Energy, systems
Secondary Programme	DP Physics
Syllabus Reference	A.3 Work, energy, power
NGSS (HS)	HS-PS3-3 · SEP 2, SEP 6 · CCC 4, CCC 5
NGSS (MS)	MS-PS3-5
Summary	Pulleys and mechanical advantage



OVERVIEW

A hoist is a block and tackle: a rope threaded back and forth between a fixed pulley block and a movable one, so that the load hangs from several strands at once instead of from a single rope. Cranes on building sites, theatre fly systems, sailing-boat mainsheets and garage engine lifts are all the same machine, and all of them exist for the same reason — a person can pull hard for a short time but cannot pull with a force of several hundred newtons at all. The principle is that the load's weight is shared equally between the strands that support the movable block. With five such strands, each carries a fifth of the weight, and since the free end of the rope is simply the last of those strands, the hand pulls only a fifth as hard. Nothing is gained for nothing: to raise the load by 20 cm, each of the five strands must shorten by 20 cm, so a full metre of rope has to be pulled through. The machine multiplies force and divides distance, and the product of the two — the work — is what it cannot change. What a real hoist can do is lose some of that work to friction in the axles and to the weight of the movable block it must lift along with the load, and the fraction that survives is its efficiency.

OBJECTIVES

- Understanding how a block and tackle multiplies force
- Applying Newton's laws to a system in equilibrium
- Measuring force and displacement
- Work, energy and efficiency
- Interpreting a trend across a series of loads

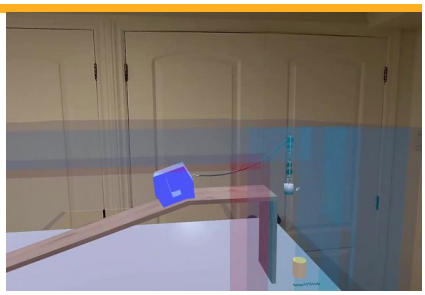
WHAT STUDENTS DO

- Load the hoist — suspend a 1 N weight from the movable pulley block, pull the dynamometer at steady speed, and record the force.
- Build the data set — repeat in 1 N steps up to 9 N, recording the ratio of load weight to driving force each time.
- Calculate efficiency — for a 1.0 m pull that lifts the load 0.200 m, compute W and Ep; efficiency is roughly 89 percent.

Lab page: proteus-vr.com/labslist/086-the-operation-of-a-hoist/

087 — Mechanical advantage in theater stage design

IB Programme	Physics — Energy, systems
Secondary Programme	DP Physics
Syllabus Reference	A.4 Mechanics
NGSS (HS)	HS-PS3-3; HS-ETS1-2 · SEP 2, SEP 6 · CCC 4, CCC 6
NGSS (MS)	MS-PS3-5
Summary	Engineering applications of pulleys



OVERVIEW

Every theatre with a fly tower runs on counterweights. A piece of scenery, a lighting bar or a performer is moved not by a motor but by a mass on the other end of a line, and the stage technician's craft is choosing that mass so that the move takes the time the director asked for, arrives where it should, and never runs away. The same arithmetic governs a funicular railway, a lift, a sash window and a crane — wherever a heavy thing is balanced against another heavy thing through a rope and some pulleys. Two pieces of physics meet here. The first is the block and tackle: with five strands supporting the movable block, the force is multiplied by five and the distance divided by five, so the counterweight moves a fifth as far as the load and pulls five times as hard. The second is Newton's second law applied to a system that is not in equilibrium. A counterweight that exactly balanced the scene would hold it still; to make it move in a set time the counterweight must be deliberately heavier than balance, and the surplus is what accelerates both masses and overcomes the friction of the ramp. Because the two ends are tied together by the rope, their accelerations are locked in the same 5 : 1 ratio as their displacements.

OBJECTIVES

- Reading a machine as a constraint between two bodies
- Building and using free-body diagrams
- Applying the kinematics of uniform acceleration
- Designing to a specification
- Accounting for friction and losses
- Relating the model to the stage

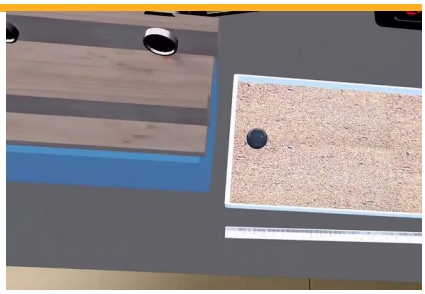
WHAT STUDENTS DO

- Run the demonstration — suspend a counterweight on the five-strand hoist, start the demonstration, and measure travel time and both displacements.
- Find the accelerations — use $\Delta x = \tfrac{1}{2}a\Delta t^2$ to obtain 0.375 m/s^2 for the gondola and 0.075 m/s^2 for the counterweight.
- Specify the mechanism — resolve gravity and friction to find $T \approx 846$ N, then a 435 kg counterweight falling 2.40 m.

Lab page: proteus-vr.com/labslist/087-mechanical_advantage_in_theater_stage_design/

088 — The relationship between the resultant force and acceleration

IB Programme	Physics — Forces
Secondary Programme	DP Physics
Syllabus Reference	A.2 Forces and momentum
NGSS (HS)	HS-PS2-1 · SEP 4, SEP 5 · CCC 2
NGSS (MS)	MS-PS2-2
Summary	Projectile motion exploration



OVERVIEW

When a ball rolls off the end of a table it does two things at once, and the whole of projectile motion rests on the fact that these two things do not interfere with each other. Horizontally it keeps the speed it left with, because nothing pushes it forwards or backwards. Vertically it falls exactly as it would have fallen from rest, because gravity does not care that it is also moving sideways. A ball rolled gently off a bench and one fired hard off the same bench hit the floor at the same moment; only the distance out from the bench differs. This independence is what lets ballistics, long-jump technique and the trajectory of a thrown javelin be calculated at all. The consequence is a strikingly simple prediction. The time in the air is fixed entirely by the drop height: $h = \frac{1}{2}gt^2$ gives $t = \sqrt{(2h/g)}$, the same for every launch from the same bench. The horizontal distance is then whatever that fixed time buys at the launch speed, $\Delta x = v \times t = v \times \sqrt{(2h/g)}$.

OBJECTIVES

- Understanding projectile motion as two independent problems
- Measuring a speed with a pair of sensors
- Applying the kinematic equations
- Building and interpreting a graph
- Evaluating errors and their direction
- Relating the result to the world outside the laboratory

WHAT STUDENTS DO

- Prepare the apparatus — fix the two sensors to the straight section of the rail, then measure the rail height and the sensor spacing.
- Launch and measure — set the launcher intensity to 1, release the ball, and measure the horizontal distance to the point of impact.
- Repeat and plot — repeat seven more times at increasing intensity, then plot Δx against v_x to confirm a line through the origin.

Lab page: proteus-vr.com/labslist/088-the-relationship-between-the-resultant-force-and-acceleration/

091 — Kinetic energy

IB Programme	Physics — Energy and Movement
Secondary Programme	DP Physics
Syllabus Reference	A.3 – Work, energy, power
NGSS (HS)	HS-PS3-1; HS-PS3-2 · SEP 5, SEP 6 · CCC 5
NGSS (MS)	MS-PS3-1
Summary	Projectile motion and the role of air resistance

OVERVIEW

This laboratory explores the principles of projectile motion and investigates the role of air resistance in real-world conditions. Projectile motion describes the movement of an object launched into the air under the influence of gravity. In an idealized model, the only force acting on the object after launch is gravity, resulting in a predictable parabolic trajectory. However, in practical situations, additional forces such as air resistance can influence the motion and lead to deviations from theoretical predictions. In this experiment, a marble is launched from a ramp equipped with a descending ramp inclined at 31°, launching from an ascending ramp inclined at 45° whose lip sits 12 cm above the sand, and its motion is observed as it travels through the air and lands in a sandbox. By varying the starting position of the marble along the ramp, students modify the initial conditions of the motion, particularly the exit speed. These variations allow for the investigation of how physical parameters such as time of flight, horizontal distance, and exit velocity influence the trajectory. The laboratory emphasizes the comparison between theoretical calculations and experimental measurements.

OBJECTIVES

- Understanding projectile motion
- Application of kinematic equations
- Analysis of initial conditions
- Experimental measurement and data collection
- Comparison between theory and experiment

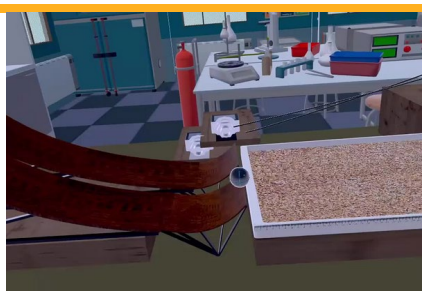
WHAT STUDENTS DO

- Place the sensors — set one timing gate on the board at the end of the ramp and the second at the far end of the sandbox.
- Run four releases — release the marble from 0.47, 0.37, 0.28 and 0.19 m, recording flight time, distance and exit speed.
- Compare with theory — compute the drag-free values, then express each measured result as a percentage of the prediction.

Lab page: proteus-vr.com/labslist/091-kinetic-energy/

106 — Rolling motion on inclined ramps

IB Programme	Physics — Motion
Secondary Programme	DP Physics
Syllabus Reference	A.1 Kinematics
NGSS (HS)	HS-PS2-1; HS-PS3-2 · SEP 4, SEP 5 · CCC 5
NGSS (MS)	MS-PS2-2
Summary	Rolling motion and energy conservation



OVERVIEW

A rolling object carries its energy in two places at once, and that single fact sets almost every number in this laboratory. Gravity roller conveyors in warehouses, ball bearings, bobsled and skateboard tracks and the gravity-fed marble runs used to teach mechanics all depend on knowing how fast a rolling body will be travelling at the foot of a slope — and a rolling body never arrives as fast as a sliding one released from the same height. When a body slides without friction, every joule of gravitational potential energy it gives up becomes translational kinetic energy. When it rolls without slipping, that same energy has to be shared with rotation, because the contact surface exerts the friction torque that spins the body up. For a solid sphere the rotational share is a fixed two sevenths of the total, leaving only five sevenths to drive the sphere forward. This is the origin of the factor 10/7 that runs through the whole laboratory: it replaces the familiar $v = \sqrt{(2gh)}$ of the sliding case with $v = \sqrt{(10gh/7)}$, about 15 % slower. Because gravity is a conservative force, the shape and the length of the slope are irrelevant to that speed — only the vertical drop matters.

OBJECTIVES

- Rolling motion and the sharing of energy
- Prediction from conservation of mechanical energy
- Kinematics of the launch and the flight
- The influence of ramp geometry
- Measurement with photodiode gates and an electronic timer
- Comparison of model with measurement

WHAT STUDENTS DO

- Predict the speeds — use the rolling-motion equation to estimate 1.91 m/s on ramp 1 and 2.19 m/s on ramp 2.
- Measure base speed — position the timing sensors, press button A, release the marble on each ramp, and read the recorded speed.
- Measure launch height — press button B on each ramp and compare the measured peak heights with the predicted 0.17 and 0.20 m.

Lab page: proteus-vr.com/labslist/106-rolling-motion-on-inclined-ramps/