Advanced Physics 2 through Inquiry

Experiment Guide

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INTRODUCTION

PASCO scientific's *Advanced Physics 2 through Inquiry* manual includes investigations designed to move students from the low level task of memorization or confirmation of science facts, to higher-level tasks of experiment design, data analysis, concept construction, and application. For science to be learned at a deep level, it is essential to combine the teaching of abstract science concepts with "real-world" science investigations. Hands-on technology-based laboratory experiences serve to bridge the gap between the theoretical and the concrete, driving students toward a greater understanding of natural phenomena. Students also gain important science process skills that include: developing and using models, planning and carrying out independent investigations, interpreting data, and using mathematics.

The laboratory activities span the physics content as defined by the College Board® for AP® Physics 2. These activities introduce students to the tools of science and help develop conceptual understanding and link the academic content of college level physics to the experimental evidence that defines and supports this content. These activities have been selected and structured to support student achievement on the end-of-year AP® Physics 2 exam.

Three Levels of Scientific Inquiry

Sixteen laboratory activities cover topics in fluids, kinetic theory, gas laws, geometrical optics, electric and magnetic fields, electromagnetic induction, capacitors and RC circuits, and modern physics. Every activity is presented in three distinctly different formats, each with a varied level of inquiry-based content:

Structured: This traditional format provides students a concise background section and a formal step-by-step setup and procedure. The *Structured* format also includes a complete equipment list and data analysis procedure with prescribed data display forms and data manipulation techniques.

Guided Inquiry: With no prescribed setup or procedure, the *Guided Inquiry* format contains a series of questions designed to invoke inquiry in students that will guide them to a proper setup and execution. Students design their own setup and procedure while also deciding how they will present their data to properly fulfill the lab objective and correctly address the lab's driving question. This format does *not* include a background section.

Student Designed: This format includes simply a driving question, objective statement, and a suggested equipment list. Students are expected to design and execute their own setup and procedure with little or no guidance from the student handout. They choose how to present their data in a way that supports their answer to the driving question, while also fulfilling the lab objective. This format does *not* include a background section.

The three different formats for each lab activity support the instructional need to differentiate the level of scientific inquiry in the classroom. Teachers may choose first to provide activities in the *Structured* format where students receive full guidance while developing skills that include critical thinking (posing good questions, developing experimental strategies, finding and fixing operational errors), procedural expertise (calibrating equipment, collecting data), proficiency in design and construction (assembling apparatus, following safety procedures), and analytical skills (graphing, modeling, statistics).

Students can then progress to a more inquiry-based approach by carrying out subsequent activities in their *Guided Inquiry* formats. When students have formed the skills necessary to confidently design and build their own experiments without help from student handouts, the *Student Designed* format can be offered to provide students a nearly *open-inquiry* approach to the lab topics.

Each lab activity, regardless of the format, contains two assessment question sections—Analysis Questions and Synthesis Questions—that are identical and applicable to all of the three handout formats. These sections are explained in more detail in the Lab Activity Components section below. In addition to supporting the scientific inquiry process, the *Advanced Physics 2 through Inquiry* activities fulfill STEM education requirements by bringing together Science, Technology, Engineering, and Math in varying degrees in the lab activities. The use of sensors, data analysis and graphing tools, models and simulations, and work with instruments, all support scientific inquiry as implemented in a STEM-focused curriculum.

Manual Components

The *Advanced Physics 2 through Inquiry* lab manual offers five major components:

Student Lab Activity Handouts. Each of the lab activities has three independent student handouts, one for each of the three inquiry-based formats: *Structured*, *Guided Inquiry*, and *Student Designed*. All student handouts are available in Microsoft® Word format, allowing teachers to customize the labs for their curriculum, students, and equipment. All student handout files are available on the electronic storage device that comes with the printed *Advanced Physics 2 through Inquiry* manual. Refer to the Lab Activity Components section below for details on each handout.

Teacher Resources. Every lab activity has an accompanying *Teacher Resources* document that contains teacher-centered content specific to the activity, including alignments to the AP® Physics 2 Learning Objectives and Science Practices[1]; recommended time requirements for teacher preparation and student data collection; a procedural overview of the procedure in the *Structured* version of the lab activity; safety and lab preparation instructions (if applicable); teacher tips; sample data for the *Structured* version procedure; responses to the *Structured* version Data Analysis questions, *Guided Inquiry* version Guided Inquiry questions, and Analysis and Synthesis questions for all versions; and extended inquiry activity suggestions.

All *Teacher Resources* documents are available in PDF format on the electronic storage device that comes with every printed *Advanced Physics 2 through Inquiry* manual. Refer to the Lab Activity Components section below for further details on teacher resources.

Student Experiment Design Plan Handout. Students following the *Guided Inquiry* or *Student Designed* version of a lab activity can use this one-sheet handout to help design and implement their inquiry-based investigation. The handout provides students with a small amount of guidance and structure as they develop their own laboratory investigation, regardless of the lab topic. Students use this handout to identify important facets of their investigations: the objective of the lab activity; what variables should be part of their potential experiment; what variables should be manipulated and controlled; how these variables will be manipulated or controlled; and how they will structure their data analysis. This handout is available in PDF format on the electronic storage device that comes with the manual.

Probeware Resources Videos. Included in every lab activity handout are links (both URL and QR code) to short, equipment-specific videos that outline the functionality, specifications, and different use-cases of most of the PASCO hardware and probeware to be used. These information-rich videos will help students understand the functionality and applications of each piece of equipment before using it. The videos will also be a useful tool for students when they design their own inquiry-based investigations. These videos are hosted online and are also available on the electronic storage device that comes with the manual.

[1] From AP Physics 1 and 2 Course and Exam Description, Effective Fall 2014. Copyright © 2014 The College Board. Reproduced with permission. http://apcentral.collegeboard.com

PASCO Capstone™ and SPARKvue® Configuration Files. Although the *Structured* version of every lab activity in the manual includes instructions on how students should display and present their data (for example, in a table or a graph), students also have access to configuration files. Each SPARKvue and PASCO Capstone configuration file has been pre-configured to have the correct display type, sample rate, and other software components needed for each lab activity. With these configuration files, students can simply connect their sensors, open the corresponding configuration file, and begin recording data. These files are available on the electronic storage device that comes with the manual.

Lab Activity Components

Each lab activity consists of four documents: the *Teacher Resources* document and the three Student Handout formats: *Structured*, *Guided Inquiry*, and *Student Designed*.

Sections in each set of activity documents: Teacher Resources, Structured, Guided Inquiry, and Student Designed

SECTIONS	TEACHER RESOURCES	STRUCTURED FORMAT	GUIDED INQUIRY FORMAT	STUDENT DESIGNED FORMAT
Connections to the AP® Physics 1 Curriculum				
Time Requirement				
Prerequisites				
Driving Question | Objective				
Procedural Overview				
Pre-Lab Discussion and Activity				
Design and Conduct Your Experiment				
Materials and Equipment			**	**
Probeware Resources			**	**
Background				
Safety	*	*		
Lab Preparation				
Teacher Tips				
Procedure				
Sample Data				
Data Analysis				
Guided Inquiry/Guiding Questions				
Experimental Design				
Assessment Questions: Sample Responses				
Analysis Questions				
Synthesis Questions				
Extended Inquiry Suggestions				

* This section is present if safety considerations are needed.

** These materials, equipment, and probeware resources are recommended, not required.

Teacher Resources Document

This document contains all of the teacher-centered information regarding the lab activity: preparation instructions, sample data, and sample responses to the questions in all student versions of the lab activity. Each *Teacher Resources* document contains the following sections:

- **Connections to the AP® Physics 2 Curriculum** – Every lab is correlated to one or more Learning Objective identified in the AP® Physics 2 curriculum framework from the *AP® Physics 1 and 2 Course and Exam Description*, Effective Fall 2014. This section lists each Big Idea, Enduring Understanding, Essential Knowledge, Learning Objective, and Science Practice applicable to the lab activity.
- **Time Requirements** – Two time frames are defined: the length of time needed for teacher preparation, and the recommended time allotment for students to complete the procedure outlined in the *Structured* version of the lab activity. If there is no specific lab preparation needed, ten minutes is designated to take into account the time required for gathering the materials, making copies of the student handout, and any other normal preparations. Note that more or less time may be required for students to finish data collection when using the *Guided Inquiry* or *Student Designed* versions.
- **Prerequisites** – This section details the concepts students should know before doing the activity. Use this section to gauge when to include this activity in lesson plans, in assessing requirements for prior learning, and as an outline for a review or discussion before starting the lab activity.
- **Driving Question | Objective** – This is the driving question and lab objective that students address when performing their laboratory investigation. This section is the same for all three student handout formats as well as the *Teacher Resources* document.
- **Procedural Overview** – This section is a summary of the procedure students follow using the *Structured* version of the lab activity, how they present their data, and the results and conclusions to be drawn from that data.
- **Pre-Lab Discussion and Activity** – The pre-lab discussion, activity, or both, are designed to accomplish some or all of the following: engage student attention; access prior knowledge; identify misconceptions; model correct lab technique; model procedures for mathematical computations required in the activity; generate student questions. This section may include pre-lab homework questions that help prepare students to carry out the lab activity.
- **Materials and Equipment** – This section lists all student materials and equipment needed per student group to carry out the procedure in the *Structured* version of each lab activity. Items that need to be prepared by the teacher or created using additional materials are called out in the Lab Preparation section of this document. Items included as part of a kit or as part of another product are highlighted with a number connecting them to the information provided in the Probeware Resources section.
- **Probeware Resources** – URLs and QR codes link to equipment-specific videos that outline the functionality, specifications, and different use-cases of most of the hardware and probeware that appear in each activity. Videos are hosted online and are also available on the electronic storage media that comes with the printed manual. The URL links and QR codes in the *Teacher Resources* document are found in all three student handout formats.
- **Safety** – This section lists the pertinent safety procedures, if any are needed, for each lab activity beyond a classroom's normal laboratory safety procedures. The Safety section found in the *Teacher Resources* document may include additional safety considerations the teacher should be aware of. This section is also found in the *Structured* version of the lab.
- **Lab Preparation** – If applicable, this section includes teacher-directed lab preparation instructions that are either required or suggested to help minimize preparation time.

- **Teacher Tips** – Depending on the activity, this section includes any or all of the following: 1) common misconceptions that students have regarding the lab topic; 2) skill requirements for using equipment; 3) difficulties students may encounter executing the lab and how to avoid or correct them; and 4) strategies and techniques for substituting items in the Materials and Equipment list that students may not have access to.
- **Sample Data** – This section is identical to the Procedure and the Data Analysis sections in the *Structured* version, with the addition of sample sensor data, tables, and graphs, answers to the questions in the Data Analysis section, and sample calculations used to process or manipulate the data.
- **Guided Inquiry Questions** – This section includes sample responses and teacher-information pertaining to the questions in the Guiding Questions section of the *Guided Inquiry* version of the lab activity.
- **Assessment Questions: Sample Responses** – This section includes sample or correct responses to the questions in the Analysis Questions and Synthesis Questions sections in all three versions of the student handouts.
- **Extended Inquiry Suggestions** – These suggestions are natural extensions of the activity and can be used for further student inquiry. They include ideas for further experimentation and hands-on exploration, classroom debates, field trips, or research papers.

Structured Format Student Handout

This is the traditional "cookbook" version of each lab activity containing the least amount of student-directed learning. Each *Structured* student handout contains the following sections:

- **Driving Question | Objective** – Each lab activity begins with a driving question and objective statement on which students will base their investigation of the scientific topic. This section is the same for all three student handout formats.
- **Materials and Equipment** – This section lists all student materials and equipment needed per student group to carry out the procedure outlined in the *Structured* version of the lab activity. In this section also are URL and QR code links to equipment-specific videos that outline the functionality, specifications, and different use-cases of the PASCO hardware and probeware used in the activity. Videos are hosted online and are also available on the electronic storage media that comes with the manual. The same Materials and Equipment list, URL links, and QR codes are found in all student handout formats.
- **Background** – The Background section appears only in the *Structured* version of each lab activity and contains information related to the scientific topic being investigated. The information frames the activity for students in the context of related curriculum materials. For broader and deeper information on a topic, students should refer to textbooks or other reference materials.
- **Safety** – If applicable, this section lists the pertinent safety procedures for each lab activity beyond a classroom's normal laboratory safety procedures. The Safety section found in the *Teacher Resources* document may include additional safety considerations the teacher should be aware of.
- **Procedure** – This section directs the student hands-on portion of each lab activity. Students follow numbered tasks to complete the procedure. Depending on the lab activity, the procedure may be divided into parts. Each part in a lab activity has a Set Up section in which students are given instructions on assembling laboratory equipment, including hardware, sensors (probeware), and data collection systems (see Using Data Collection Technology). Each part also contains a Collect Data section with instructions on how and when to collect data, and where to record data in the Data Analysis section.

- **DATA ANALYSIS** – In this section, students are instructed to analyze and present their data in ways specific to the lab activity, such as completing a data table, making calculations to manipulate or process data, plotting or sketching graphs of data, or identifying key parts of the data plots. In addition, several of the activities in this manual employ a data linearization technique found in AP® Physics 1 and 2 exams.
- **ANALYSIS QUESTIONS** – These questions help students understand their collected data as it pertains to the lab topic and driving question. Students make comparisons, summaries, arguments, and conclusions regarding the scientific concept using their data for verification. This section is the same for all student handout formats.
- **SYNTHESIS QUESTIONS** – These questions help students integrate information and concepts explored in the lab activity with information from other topics using real-world scenarios. Students develop a deeper understanding of concepts as they transfer knowledge learned in the lab to other situations. Some questions may require students to consult available resources, such as textbooks, reference books, resources on the Internet, and local experts. This section is the same for all student handout formats.

Guided Inquiry Format Student Handout

The *Guided Inquiry* format, compared to the traditional version, is a more student-directed approach. The step-by-step Procedure and Data Analysis sections found in the *Structured* format are replaced with a set of guiding questions intended to help students design their own procedure and analysis strategies. The *Guided Inquiry* student handout contains the following sections:

- **DRIVING QUESTION | OBJECTIVE** – Each lab activity begins with a driving question and objective statement on which students will base their investigation of the scientific topic. This section is the same for all student handout formats.
- **DESIGN AND CONDUCT YOUR EXPERIMENT** – Instead of following a step-by-step procedure, students are directed to design an experiment that fulfills the lab objective, and whose data will support their answer to the driving question. Although the same materials and equipment list found in the *Structured* version also appears in this section, it is presented as suggested equipment. Students using the *Guided Inquiry* or *Student Designed* formats will have the freedom to choose any reasonable equipment at their disposal. This section is the same in the *Guided Inquiry* and *Student Designed* formats.
- **GUIDING QUESTIONS** – This section contains a series of questions designed to stimulate inquiry in students that will guide them to determine their experiment design. Although these questions will vary depending on the lab activity, most questions help students: identify variables that will be part of their experiment; define which variables to manipulate and which variables to control; determine how each variable can be measured, how data should be collected and in what order, and how to manipulate, process, and present data to isolate values of interest and identify unknowns. Along with each set of guiding questions, you may also choose to provide students with the *Experiment Design Plan* handout (refer to the Manual Components) to help facilitate the experimental design process.
- **EXPERIMENTAL DESIGN** – This section is divided into the Setup, Procedure, and Collect Data subsections in which students document the experimental setup and procedure they have chosen, and present any data that is part of their experiment. This section is the same in both the *Guided Inquiry* and *Student Designed* formats.
- **ANALYSIS QUESTIONS** – See the corresponding section in the *Structured Format Student Handout* above. This section is the same for all three student handout formats.
- **SYNTHESIS QUESTIONS** – See the corresponding section in the *Structured Format Student Handout* above. This section is the same for all three student handout formats.

Student Designed Format Student Handout

This format is the most student-directed version of a lab activity, containing the least amount of instruction and assistance. Students are responsible for designing and executing their own experimental setup and procedure with little or no guidance from the student handout. Students choose how to present their data in a way that supports their answer to the driving question, while also fulfilling the lab objective.

Each *Student Designed* handout contains the same sections found in the *Guided Inquiry* format except it has no Guiding Questions section.

Conducting Successful Inquiry-Based Lab Activities

Establish the Foundation

Preparing students to conduct their own scientific inquiry activities takes time and intention. Students need a foundation in conceptual development, laboratory bench skills, using electronic data collection and display equipment, and interpreting data. The following strategies help students build this foundation:

- Work with students to complete tutorials for equipment and software they will be using.
- Demonstrate the first few activities using the *Structured* or *Guided Inquiry* formats so you model the correct use of equipment and materials.
- Work with students to complete all sections of several lab activities until they understand your expectations.
- Create teams, giving defined responsibilities to members. (A key behavioral component of a STEM curriculum experience is that students work in teams and successfully solve problems as a team.) Devise a method to track the roles each student carries out, such as a team leader, a recorder, and a technician. Make sure each student has multiple opportunities to perform each role.
- Create opportunities for students to repeat activities that seemed beyond their grasp the first time through—perhaps with student-suggested modifications. You will see substantial improvement as students are given increased opportunities to work with the equipment and analyze the data.

Foster Inquiry Skills

Foster the growth and development of inquiry skills. Provide multiple opportunities for students to work with the equipment, analyze data, and communicate and discuss conclusions. The following strategies support development of laboratory and data analysis skills:

- Model the more complex technical tasks, such as mathematical computations.
- Provide multiple and varied opportunities for practice with hands-on activities using the data collection tools.
- Compile and compare class data whenever possible. Discuss the sources of variation in data and the best interpretation of the data.
- Challenge students to identify applications of the concept just studied.
- Have students brainstorm related questions they would like to explore in their own investigations.

Cultivate Student-Directed Inquiry

At the heart of an effective STEM curriculum is the cultivation of inquiry skills in students. As students complete instructor-directed activities in this manual (using the *Structured* and *Guided Inquiry* formats), their interest may be stimulated regarding one or more issues. Watch for these moments and provide students with assistance for generating their own driving questions and related objectives. For either students' own questions or for those provided in the *Student Designed* format of the lab activities, use the following strategies:

- Require a written plan with procedures. Review these plans and guide students accordingly. Make sure students define projects that are practical under the conditions of your classroom environment.
- Provide plenty of time, material, and equipment resources.
- Incorporate check points to assess progress.
- To guide the students, ask questions such as those in the *Guided Inquiry* version of each lab.

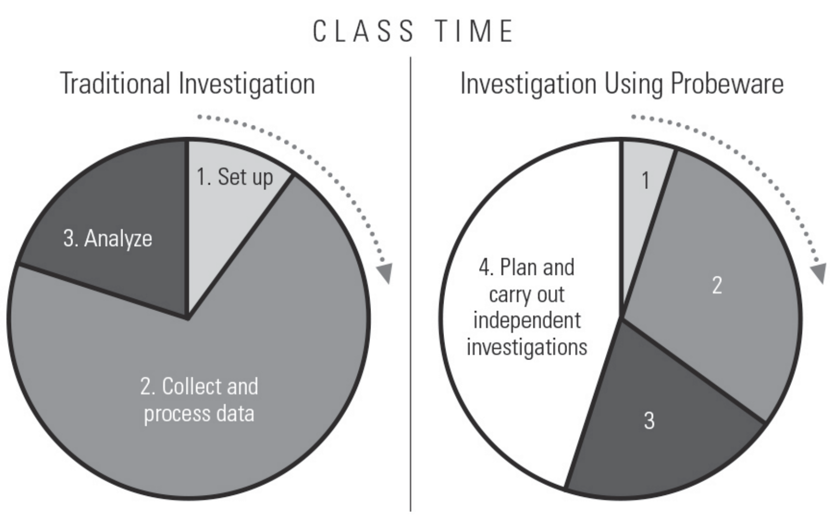
Communicate the Results of Student-Directed Inquiry

Provide opportunities for students to communicate the results of student-directed inquiry. Strategies include:

- Formal research papers, PowerPoint® presentations, video productions, and poster presentations are ways for students to share what they have learned.
- Student-directed inquiries related to community resources may be of interest to area news or conservation groups. Have students report on their findings in a community venue such as the school website or newspaper, local newspapers, or other publications.

Using Data Collection Technology

The use of electronic sensors (probeware) in investigations greatly reduces the class time required for set up and data collection, increases the accuracy of results, allows for richer analysis of data, and provides more time in the classroom for independent investigations.



Additionally, using electronic-sensor data collection, display, and analysis devices allows students to focus not on the tedium of collecting data, but rather on the trends, patterns, and relationships which become immediately discernible when gathering real-time data.

The Data Collection System

In this manual, *data collection system* refers to the system students use to record, visualize, and analyze sensor data during their experiments. The system consists of all components necessary to connect a sensor to a device containing the software that detects the sensor measurement and collects, records, and displays the data.

Some systems, such as the Xplorer GLX® or SPARK Science Learning System™, are stand-alone systems. These contain built-in software applications and students simply attach a sensor and begin collecting data. Other systems use a computer or tablet with downloaded software applications. In these systems, a USB or Bluetooth® interface is used to connect a sensor to the device. Software options for these include SPARKvue and PASCO Capstone software.

The activities are designed so that any PASCO scientific data collection system can be used to carry out the procedures.

Getting Started with Your Data Collection System

To become familiar with the many features of your data collection system, start with the tutorials and instructional videos available in the video library on the PASCO scientific website (www.pasco.com). Also, each system's software has a built-in help system.

There are free SPARKlab™ activities included in the SPARKvue software. Performing one of these activities can be a good starting place for students to familiarize themselves with connecting a sensor, viewing data, saving their work, and other tasks related to probeware use.

PASCO scientific also has a terrific technical and teacher support team. They pride themselves on providing timely and comprehensive help to teachers and students using PASCO scientific products.

Phone: 1-800-772-8700

Email: support@pasco.com

Web: www.pasco.com/support

Inside the Printed Manual

The printed *Advanced Physics 2 through Inquiry* lab manual includes the following documents:

- *Table of Contents*
- *Introduction*
- *Master Materials and Equipment List*
- *Experiment Design Plan* handout
- *Teacher Resources* for each of the lab activities
- *Structured* format student handout for each of the lab activities

Documents *not* printed but available on the accompanying electronic storage device are:

- *Guided Inquiry* format student handout for each of the lab activities
- *Student Designed* format student handout for each of the lab activities

Electronic Materials

The electronic storage device accompanying this manual contains the following:

- Complete *Advanced Physics 2 through Inquiry* manual in PDF format (Acrobat™ compatible)
- Each lab activity's *Teacher Resources* document in PDF format.
- Student handout versions of each laboratory activity in all three formats (*Structured*, *Guided Inquiry*, and *Student Designed*) in an editable Microsoft Word format. PASCO scientific provides editable files of the student lab activities so that teachers can customize activities to their needs.
- Student *Experiment Design Plan* handout in PDF format.
- A complete set of the Probeware Resources Videos used in the *Advanced Physics 2 through Inquiry manual*. Although these videos are hosted online, PASCO scientific provides them in MP4 format for those who may not have a reliable Internet connection, or cannot access videos due to internal system or website restrictions.
- PASCO Capstone and SPARKvue Configuration Files for every lab activity.

AP® Physics 2 Correlations

Below is a list of the 16 lab activities in the *Advanced Physics 2 through Inquiry* lab manual. In the right columns of the table are the correlations for each lab activity to the AP® Concept Outline found in the *AP Physics 1 and 2 Course and Exam Description*, Effective Fall 2014 curriculum framework published by the College Board®.

Each reference number indicates the Big Idea, Enduring Understanding, Essential Knowledge, and Learning Objective to which the activity is correlated. For example "3.B.1.2" indicates that the activity is correlated to Learning Objective 2 found within the first Essential Knowledge statement, which is within Enduring Understanding B, and in turn part of Big Idea 3. Shown in the column to the right of the Learning Objectives are the applicable Science Practices identified by the College Board® based on each correlated Learning Objective.

International Baccalaureate Organization (IBO) Support

The International Baccalaureate Organization (IBO) uses a specific science curriculum model that includes both theory and practical investigative work. While this lab guide was not produced by the IBO and does not include references to the IB internal assessment rubrics, the lab activities can be adapted easily to the IB classroom. The labs in this manual correlate closely to core and optional topics of the IB Physics standard level and higher level programs: fluid dynamics, optics and imaging, electromagnetic induction, quantum physics, and others. These correlations are listed in the table below.

By the end of the IB Diploma Program, students are expected to have completed a set number of practical investigative hours and are assessed using the specified internal assessment criteria. Students should be able to design a lab based on an original idea, carry out the procedure, draw conclusions, and evaluate their results. These scientific processes require an understanding of laboratory techniques and equipment as well as a high level of thinking, skills that are developed and sharpened by completing the investigations in this manual.

AP® Physics 2 and IBO correlations to the activities in this manual

Activity Number	Activity Name and Description	AP® Physics 2 Learning Objective	AP® Physics 2 Science Practice	IBO Standard
1	Hydrostatic Pressure *Students use a low-pressure sensor to measure the static pressure at different depths in a column of water and use their data to determine the mathematical relationship between static pressure and depth in a fluid.*	3.C.4.1 3.C.4.2	6.1 6.2	B.3
2	Buoyant Force *Students use a high-resolution force sensor to measure the buoyant force on a metal cylinder lowered into a fluid and then determine the relationship between the buoyant force on a submerged object and a) its volume and b) the weight of the fluid displaced by the submerged object.*	1.E.1.2 3.A.3.1 3.C.4.2	4.1 6.2 6.4 7.2	B.3
3	Fluid Dynamics *Students determine the relationship between the velocity of a water stream as it leaves the nozzle at the bottom of a water column and the height of the water column.*	5.B.10.1 5.B.10.3 5.B.10.4	2.2 6.2	B.3
4	Boyle's Law *Students use a low-pressure sensor and a syringe to determine the inverse proportionality between the pressure and volume of an enclosed gas.*	5.B.7.2 7.A.3.2 7.A.3.3	1.1 3.2 4.2 5.1	3.2
5	Spherical Mirror Reflection *Students use an optics light source, optics track, and half screen to measure the image and object distances associated with the real image formed by a concave spherical mirror and then use principles of reflection and the spherical mirror equation to determine the mirror's radius of curvature.*	6.E.4.1 6.E.4.2	3.2 4.1 4.2 5.1 5.2 5.3	C.1
6	Snell's Law *Students use an optics ray table to measure the incident and refraction angles of a light ray travelling from air into a material with unknown index of refraction, and then, using the principles of refraction and Snell's law, they determine the material's index of refraction.*	6.E.3.2 6.E.3.3	4.1 5.1 5.2 5.3 6.4 7.2	4.4
7	Focal Length of a Converging Lens *Students use an optics light source, optics track, and viewing screen to measure the image and object distances associated with the real image formed by a converging lens, and then determine the focal length of the lens.*	6.E.5.1 6.E.5.2	1.4 2.2 3.2 4.1 5.1 5.2 5.3	C.1
8	Interference and Diffraction *Students shine laser light through a double-slit aperture onto paper, measure the distances between the maxima of the resulting interference pattern, and use the principles associated with double-slit interference and diffraction to determine the spacing between the slits.*	6.C.3.1	1.4 6.4	4.4 9.2 9.3
9	Electric Field Mapping *Students use a DC power supply and semi-conductive paper to create dipole and parallel plate electrodes, and then use the principles of electric fields and electric potential energy to determine the shape and direction of the electric field lines in each configuration.*	2.E.2.1	6.4 7.2	5.1 10.1

Activity Number	Activity Name and Description	AP® Physics 2 Learning Objective	AP® Physics 2 Science Practice	IBO Standard
10	Magnetic Fields *Students use an AC/DC electronics laboratory, a power supply, and a Magnaprobe™ wand to detect and compare the magnetic field pattern surrounding a bar magnet and a current-carrying coil.*	2.D.2.1 2.D.3.1 2.D.4.1	1.1 1.2 1.4	5.4
11	Magnetic Field Strength *Students use a 2-axis magnetic field sensor and the AC/DC electronics laboratory to determine how the strength of the magnetic field at the center of a current-carrying coil depends on the coil current and radius.*	2.D.2.1	1.1	5.4
12	Electromagnetic Induction *Students use an induction wand, rotary motion sensor, variable gap magnet, and 2-axis magnetic field sensor to determine how the rate of change of magnetic flux through a coil affects the magnitude and direction of the average emf induced in it.*	4.E.2.1	6.4	11.1
13	Capacitor Fundamentals *Students use a digital capacitance meter and construct capacitors from aluminum foil and paper to determine how physical properties of a parallel-plate capacitor affect its ability to store electric charge.*	4.E.4.2 4.E.4.3	4.1 4.2 5.1	11.3
14	Series and Parallel Capacitors *Students use a capacitance meter to measure the equivalent capacitance in simple series and parallel circuits and determine the equivalent capacitance of capacitors connected in series and parallel.*	4.E.5.3 5.B.9.5	2.2 4.2 5.1 6.4	11.3
15	RC Circuits *Students use a voltage–current sensor and an AC/DC electronics laboratory to determine how the potential differences across the resistors and capacitor in a simple RC circuit differ when the capacitor is charging, discharging, and fully charged, and how these differences affect the current through each component in the circuit.*	4.E.5.1 4.E.5.2 4.E.5.3	2.2 4.2 5.1 6.1 6.4	11.3
16	Planck's Constant *Students use a voltage–current sensor and an AC/DC electronics laboratory to measure the turn-on voltage of various colors of LEDs and then plot the turn-on voltage versus LED frequency to determine the value of Planck's constant.*	6.F.3.1 6.F.4.1	6.4 7.1	12.1

MASTER MATERIALS AND EQUIPMENT LIST

This Master Materials and Equipment List shows the equipment required to perform the *Structured* version of each lab activity from the *Advanced Physics 2 through Inquiry* lab manual. Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group.

Teachers can conduct some lab activities with sensors and probes other than those listed here. For assistance with substituting compatible sensors and probes for a lab activity, contact PASCO Teacher Support (800-772-8700 inside the United States or http://www.pasco.com/support).

Lab	Title	Materials and Equipment	PASCO Part Number	Qty
1	HYDROSTATIC PRESSURE Students use a low-pressure sensor to measure the static pressure at different depths in a column of water and use their data to determine the mathematical relationship between static pressure and depth in a fluid.	**FOR EACH STUDENT STATION**		
		Data Collection System		1
		PASPORT Barometer/Low-Pressure Sensor	PS-2113A	1
		PASPORT Sensor Extension Cable*	PS-2500 or w/PS-2162	1
		Quick connector*	w/PS-2113A	1
		Tubing, 1/4" diameter*	w/PS-2113A	30 cm
		Four-Scale Meter Stick	SE-8695	1
		Water reservoir, transparent, over 30 cm high		1
		Distilled water, to fill the reservoir 3/4 full		2 L
2	BUOYANT FORCE Students use a high-resolution force sensor to measure the buoyant force on a metal cylinder lowered into a fluid and then determine the relationship between the buoyant force on a submerged object and a) its volume and b) the weight of the fluid displaced by the submerged object.	**FOR EACH STUDENT STATION**		
		Data Collection System		1
		PASPORT High Resolution Force Sensor with hook	PS-2189	1
		PASCO Overflow Can	SE-8568	1
		PASCO Aluminum Table Clamp	ME-8995	1
		Brass cylinder[1]	w/ME-8569A	1
		Aluminum cylinder[1]	w/ME-8569A	1
		Rod, 45-cm	ME-8736	2
		Right angle clamp	SE-9444	1
		Four-Scale Meter Stick	SE-8695	1
		Thread	ME-9875	60 cm
		Beaker, 100-mL		1
		Beaker, 1-L		1
		Glass stir rod		1
		Felt-tipped pen with permanent ink		1
		Liquid dish soap		3 mL
		Distilled water		500 mL
		Paper towel		1 roll
		[1]Any two metal cylinders (of different metals) that can be suspended vertically above their center can be used.		
		FOR THE ENTIRE CLASS		
		Ohaus Scout Pro Balance 400-g	SE-8756A	1

Lab	Title	Materials and Equipment	PASCO Part Number	Qty
3	FLUID DYNAMICS Students determine the relationship between the velocity of a water stream as it leaves the nozzle at the bottom of a water column and the height of the water column.	**FOR EACH STUDENT STATION** Four-Scale Meter Stick *Water reservoir with a nozzle or hole at the bottom* *Support stand, 10 cm high* *Distilled water to fill the water reservoir* *Water catch basin* *Pen, felt marker*	 SE-8695	 1 1 1 2 L 1 1
4	BOYLE'S LAW Students use a low-pressure sensor and a syringe to determine the inverse proportionality between the pressure and volume of an enclosed gas.	**FOR EACH STUDENT STATION** Data Collection System PASPORT Barometer/Low-Pressure Sensor PASPORT Sensor Extension Cable* Quick connector* Tubing* Syringe, 60-mL* *Scissors*	 PS-2113A PS-2500 or w/PS-2162 w/PS-2113A w/PS-2113A w/SE-7562	 1 1 1 1 2 cm 1 1
5	SPHERICAL MIRROR REFLECTION Students use an optics light source, optics track, and half screen to measure the image and object distances associated with the real image formed by a concave spherical mirror and then use principles of reflection and the spherical mirror equation to determine the mirror's radius of curvature.	**FOR EACH STUDENT STATION** PASCO Optics Track[2] PASCO Basic Optics Light Source PASCO Concave Mirror Accessory PASCO Half-Screen Accessory* [2]or PASCO Dynamics Track with three Optics Carriages (OS-8472)	 OS-8508 OS-8470 OS-8457 w/OS-8457	 1 1 1 1
6	SNELL'S LAW Students use an optics ray table to measure the incident and refraction angles of a light ray travelling from air into a material with unknown index of refraction, and then, using the principles of refraction and Snell's law, they determine the material's index of refraction.	**FOR EACH STUDENT STATION** PASCO Basic Optics Ray Table PASCO Basic Optics Light Source D-shaped lens*	 OS-8465 OS-8470 w/OS-8465	 1 1 1
7	FOCAL LENGTH OF A CONVERGING LENS Students use an optics light source, optics track, and viewing screen to measure the image and object distances associated with the real image formed by a converging lens, and then determine the focal length of the lens.	**FOR EACH STUDENT STATION** PASCO Optics Track[2] PASCO Basic Optics Light Source PASCO Basic Optics Viewing Screen PASCO Adjustable Lens Holder Converging lens, 50-mm diameter * [2]or PASCO Dynamics Track with three Optics Carriages (OS-8472)	 OS-8508 OS-8470 OS-8460 OS-8474 w/OS-8466A	 1 1 1 1 1

Lab	Title	Materials and Equipment	PASCO Part Number	Qty
8	INTERFERENCE AND DIFFRACTION	**FOR EACH STUDENT STATION**		
	Students shine laser light through a double-slit aperture onto paper, measure the distances between the maxima of the resulting interference pattern, and use the principles associated with double-slit interference and diffraction to determine the spacing between the slits.	PASCO Diffraction Plate	OS-8850	1
		PASCO Aluminum Table Clamp	ME-8995	2
		Rod, 45-cm	ME-8736	2
		Three finger clamp	SE-9445	2
		Stainless steel calipers	SE-8710	1
		Laser pointer with known wavelength	SE-9716B	1
		Four-Scale Meter Stick	SE-8695	1
		White paper		1 sheet
		Pencil		1
		Measuring tape		1
		FOR THE ENTIRE CLASS		
		Tape		1 roll
9	ELECTRIC FIELD MAPPING	**FOR EACH STUDENT STATION**		
	Students use a DC power supply and semi-conductive paper to create dipole and parallel plate electrodes, and then use the principles of electric fields and electric potential energy to determine the shape and direction of the electric field lines in each configuration.	PASCO Field Mapper Kit	PK-9023	1
		Conductive paper*	w/PK-9023	2 sheets
		Conductive ink pen*	w/PK-9023	1
		Cork board*	w/PK-9023	1
		Pushpin, metal*	w/PK-9023	6
		Student power supply, 18 VDC, 3 A	SE-8828	1
		4-mm banana plug patch cord*	w/SE-9750 or w/PS-2115	4
		4-mm banana plug alligator clip*	w/SE-9756 or w/PS-2115	4
		Digital multimeter	SE-9786A	1
		T-pin, metal		1
		Felt-tip marker, silver		1
		Pencil		1
10	MAGNETIC FIELDS	**FOR EACH STUDENT STATION**		
	Students use an AC/DC electronics laboratory, a power supply, and a Magnaprobe™ wand to detect and compare the magnetic field pattern surrounding a bar magnet and a current-carrying coil.	PASCO AC/DC Electronics Lab Kit	EM-8656	1
		Wire lead*	w/EM-8656	1
		Student power supply, 18 VDC, 3 A	SE-8828	1
		Magnaprobe™ wand	SE-7390	1
		Bar magnet	EM-8620	1
		4-mm banana plug patch cord*	w/SE-9750 or w/PS-2115	2
		Magnet wire or enameled wire, 22-gauge		4 m
		Sandpaper		1 sheet
		Scissors or wire cutters		1
		Beaker, 400-mL		1

Lab	Title	Materials and Equipment	PASCO Part Number	Qty
11	MAGNETIC FIELD STRENGTH Students use a 2-axis magnetic field sensor and the AC/DC electronics laboratory to determine how the strength of the magnetic field at the center of a current-carrying coil depends on the coil current and radius.	**FOR EACH STUDENT STATION**		
		Data Collection System		1
		PASPORT 2-Axis Magnetic Field Sensor w/handle	PS-2162	1
		PASPORT Sensor Extension Cable*	w/PS-2162	1
		PASCO AC/DC Electronics Lab Kit	EM-8656	1
		Wire lead*	w/EM-8656	1
		Student power supply, 18 VDC, 3 A	SE-8828	1
		4-mm banana plug patch cord*	w/SE-9750 or w/PS-2115	2
		PASCO Aluminum Table Clamp	ME-8995	1
		Rod, 45-cm	ME-8736	1
		Right angle clamp	SE-9444	1
		Four-Scale Meter Stick	SE-8695	1
		Magnet wire or enameled wire, 22-gauge		10 m
		Beakers of different diameter		5
		Sandpaper		1 sheet
		Scissors or wire cutters		1
12	ELECTROMAGNETIC INDUCTION Students use an induction wand, rotary motion sensor, variable gap magnet, and 2-axis magnetic field sensor to determine how the rate of change of magnetic flux through a coil affects the magnitude and direction of the average emf induced in it.	**FOR EACH STUDENT STATION**		
		Data Collection System		1
		PASPORT Voltage–Current Sensor	PS-2115	1
		PASPORT Rotary Motion Sensor	PS-2120A	1
		PASPORT 2-Axis Magnetic Field Sensor	PS-2162	1
		PASPORT Sensor Extension Cable*	w/PS-2162	1
		PASCO Variable Gap Magnet	EM-8618	1
		PASCO Induction Wand	EM-8099	1
		PASCO Aluminum Table Clamp	ME-8995	1
		Right angle clamp	SE-9444	1
		Rod, 45-cm	ME-8736	2
13	CAPACITOR FUNDAMENTALS Students use a digital capacitance meter and construct capacitors from aluminum foil and paper to determine how physical properties of a parallel-plate capacitor affect its ability to store electric charge.	**FOR EACH STUDENT STATION**		
		4-mm banana plug patch cord*	w/SE-9750 or w/PS-2115	2
		4-mm banana plug alligator clip*	w/SE-9756 or w/PS-2115	2
		Four-Scale Meter Stick	SE-8695	1
		Digital capacitance meter, 0.01-nF resolution		1
		Aluminum foil sheet, 8 ½" × 11"		4
		Paper sheet, 8 ½" × 11"		6
		Scissors		1
		Heavy textbook		1
14	SERIES AND PARALLEL CAPACITORS Students use a capacitance meter to measure the equivalent capacitance in simple series and parallel circuits and determine the equivalent capacitance of capacitors connected in series and parallel.	**FOR EACH STUDENT STATION**		
		PASCO AC/DC Electronics Lab Kit	EM-8656	1
		Wire lead*	w/EM-8656	6
		4-mm banana plug patch cord*	w/SE-9750 or w/PS-2115	2
		4-mm banana plug alligator clip*	w/SE-9756 or w/PS-2115	2
		Digital capacitance meter, 1-µF resolution		1
		Capacitor, 100-µF		5

Lab	Title	Materials and Equipment	PASCO Part Number	Qty
15	RC CIRCUITS Students use a voltage–current sensor and an AC/DC electronics laboratory to determine how the potential differences across the resistors and capacitor in a simple RC circuit differ when the capacitor is charging, discharging, and fully charged, and how these differences affect the current through each component in the circuit.	**FOR EACH STUDENT STATION** Data Collection System PASPORT Voltage–Current Sensor 4-mm banana plug patch cord* 4-mm banana plug alligator clip* PASCO AC/DC Electronics Lab Kit Capacitor, 470-μF* Resistor, 33-Ω* Resistor, 100-Ω* Wire lead* *D-cell Battery*	 PS-2115 w/PS-2115 w/PS-2115 EM-8656 w/EM-8656 w/EM-8656 w/EM-8656 w/EM-8656 	 1 1 2 4 1 1 1 1 6 2
16	PLANCK'S CONSTANT Students use a voltage–current sensor and an AC/DC electronics laboratory to measure the turn-on voltage of various colors of LEDs and then plot the turn-on voltage versus LED frequency to determine the value of Planck's constant.	**FOR EACH STUDENT STATION** Data Collection System PASPORT Voltage–Current sensor PASCO AC/DC Electronics Lab Kit Wire lead* Resistor, 330-Ω* *LED, blue (450–500 nm)* *LED, green (501–565 nm)* *LED, yellow/amber (566–620 nm)* *LED, red (621–750 nm)* *D-cell Battery*	 PS-2115 EM-8656 w/EM-8656 w/EM-8656 	 1 1 1 5 1 1 1 1 1 2

* These items are included with the specific kit, apparatus, or sensor used in the experiment.

ACTIVITY BY PASCO ITEM

This table indicates which lab activities use the PASCO scientific sensors or special equipment listed. The quantities shown indicate the number of each item required to complete all the activities that require the specified item.

Items Available from PASCO	PASCO Part Number	Qty	Activity Where Used
PASCO SENSORS			
PASPORT Barometer/Low-Pressure Sensor	PS-2113A	1	1, 4
PASPORT High Resolution Force Sensor with hook	PS-2189	1	2
PASPORT 2-Axis Magnetic Field Sensor	PS-2162	1	11, 12
PASPORT Sensor Extension Cable*	w/PS-2162	1	1, 4, 11, 12
PASPORT Rotary Motion Sensor	PS-2120A	1	12
PASPORT Voltage-Current Sensor	PS-2115	1	12, 15, 16
PASCO LABWARE			
PASCO AC/DC Electronics Lab Kit	EM-8656	1	10, 11, 14, 15, 16
PASCO Adjustable Lens Holder	OS-8474	1	7
PASCO Aluminum Table Clamp	ME-8995	1	2, 8, 11, 12
PASCO Basic Optics Light Source	OS-8470	1	5, 6, 7
PASCO Basic Optics Ray Table	OS-8465	1	6
PASCO Basic Optics Viewing Screen	OS-8460	1	7
PASCO Concave Mirror Accessory	OS-8457	1	5
PASCO Diffraction Plate	OS-8850	1	8
PASCO Field Mapper Kit	PK-9023	1	9
PASCO Induction Wand	EM-8099	1	12
PASCO Optics Track	OS-8508	1	5, 7
PASCO Overflow Can	SE-8568	1	2
PASCO Variable Gap Magnet	EM-8618	1	12
OTHER LABWARE			
Brass cylinder	w/ME-8569A	1	2
Aluminum cylinder	w/ME-8569A	1	2
Bar magnet	EM-8620	1	10
Converging lens, 50-mm diameter*	OS-8466A	1	7
Digital multimeter	SE-9786A	1	9
Four-Scale Meter Stick	SE-8695	1	1, 2, 3, 8, 11, 13
Laser pointer with known wavelength	SE-9716B	1	8
Magnaprobe™ wand	SE-7390	1	10
Right angle clamp	SE-9444	1	2, 11, 12
Rod, 45-cm	ME-8736	2	2, 8, 11, 12

Items Available from PASCO	PASCO Part Number	Qty	Activity Where Used
Stainless steel calipers	SE-8710	1	8
Student power supply, 18 VDC, 3 A	SE-8828	1	9, 10, 11
Syringe, 60-mL*	w/SE-7562	1	4
Thread	ME-9875	60 cm	2
Three finger clamp	SE-9445	2	8

* These items are included with the specific kit, apparatus, or other sensor.

EXPERIMENT DESIGN PLAN HANDOUT

Students following the *Guided Inquiry* or *Student Designed* version of a lab activity can use the one-sheet handout on the following page to help design and implement their inquiry-based investigation. The handout provides students with a small amount of guidance and structure as they develop their own laboratory investigation, regardless of the lab topic. The different sections and their roles are described below:

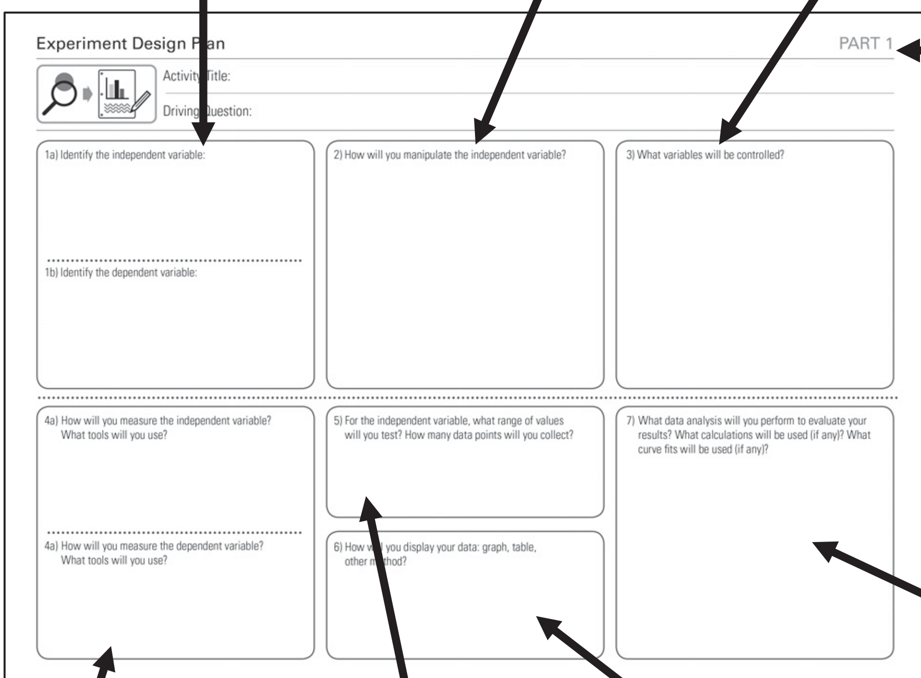
Components of the Handout

1) Students first identify the independent and dependent variables in their proposed experiment, based on the driving question.

2) Students then determine how to physically manipulate the independent variable they've chosen.

3) Students identify other variables in their proposed experiment that must be controlled so the independent variable can be isolated and tested.

The same content is repeated on the document's backside for students whose proposed experiment requires more than one configuration.



7) Students determine how they will analyze their data: Will there be any additional data manipulation (this includes linearization), calculations, curve fits, smoothing, et cetera.

4) Students determine how they will measure the independent and dependent variables in their proposed experiment, what sensors they will use, and what steps they will take to make the measurements.

5) Students determine the values for testing their independent variable. Results of too small of a range of values may prove inconclusive; using too large of a range may exceed the capabilities of their measurement tools.

6) Students then determine how best to display the data (such as a graph or table) they will collect in their proposed experiment. Students who choose to plot graphs should identify which variable to plot on the *x*-axis, and which to plot on the *y*-axis.

Experiment Design Plan

Activity Title:

Driving Question:

1a) Identify the independent variable:

1b) Identify the dependent variable:

2) How will you manipulate the independent variable?

3) What variables will be controlled?

4a) How will you measure the independent variable? What tools will you use?

4a) How will you measure the dependent variable? What tools will you use?

5) For the independent variable, what range of values will you test? How many data points will you collect?

6) How will you display your data: graph, table, other method?

7) What data analysis will you perform to evaluate your results? What calculations will be used (if any)? What curve fits will be used (if any)?

Experiment Design Plan

1a) Identify the independent variable:

1b) Identify the dependent variable:

2) How will you manipulate the independent variable?

3) What variables will be controlled?

4a) How will you measure the independent variable? What tools will you use?

4a) How will you measure the dependent variable? What tools will you use?

5) For the independent variable, what range of values will you test? How many data points will you collect?

6) How will you display your data: graph, table, other method?

7) What data analysis will you perform to evaluate your results? What calculations will be used (if any)? What curve fits will be used (if any)?

1. HYDROSTATIC PRESSURE

Connections to the AP® Physics 2 Curriculum*

The lab activity correlates to the following pieces of the AP® Physics 2 framework:

Big Idea	3	Enduring Understanding	C	Essential Knowledge	4

Learning Objective 1: The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces.
Science Practices: 6.1

Learning Objective 2: The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions.
Science Practices: 6.2

Time Requirement

Preparation Time: 15 minutes

Lab Activity: 30 minutes

Prerequisites

Students should be familiar with the following concepts:

- Pressure is the force applied to a fluid per unit area.
- Gauge pressure is the absolute pressure minus the atmospheric pressure.
- Density is the mass per unit volume of a fluid.

Driving Question | Objective

How is static pressure related to depth in a column of water? Experimentally determine the mathematical relationship between static pressure and depth in a column of water.

Procedural Overview

In the Structured version of this lab activity, students measure the pressure in a water reservoir at five different depths and record the pressure and height data in a table. After collecting data, the students graph pressure versus depth to discover a linear relationship in the data. A best-fit line is applied to the data; students learn that its slope is used to determine an experimental value for the density of the water.

Pre-Lab Discussion and Activity

Unless you are using 1000-mL graduated cylinders, it is very likely your students will be using water reservoirs that do not have a uniform shape, such as a 2-liter soda bottle. Students may question whether this introduces an additional variable. To demonstrate that the shape of the reservoir does not have any effect on the pressure measurement, take pressure measurements in water reservoirs of different shapes (see the Teacher Tips for examples), always at the same water depth. You may also want to consider having student groups use differently shaped water reservoirs for their investigations so they may compare their results.

Materials and Equipment

- Data collection system
- PASCO Barometer/Low Pressure Sensor[1]
- PASCO Sensor Extension Cable
- Quick connector[1]
- Tubing, 1/4" diameter, longer than 30-cm[1]
- Water reservoir, transparent, over 30 cm high
- Ruler
- Distilled water, to fill the reservoir 3/4 full

Probeware Resources

Below are web-link and QR codes that will direct you to instructional video resources for individual pieces of PASCO probeware, sensors, and other hardware used in the lab activity. These same links and codes are provided to students in their activity handouts.

[1]www.pasco.com/ap24

PASCO Barometer/Low Pressure Sensor

Safety

Follow this important safety precaution in addition to your regular classroom procedures:

- Make necessary arrangements to your workstation to avoid getting water on any electronic equipment.

Teacher Tips

Tip 1 – Water Reservoir

- Any transparent reservoir will work for this experiment, regardless of shape, since pressure is not dependent on volume. Examples of reservoirs: 1000-ml graduated cylinders, 2-liter soda bottles, vases, and fish tanks.

Tip 2 – Using an Absolute Pressure Sensor

- The PASCO Barometer/Low Pressure Sensor is recommended for this activity based on its measurement resolution. However, an absolute pressure sensor can also be used for this activity, although it may provide slightly less accurate results.

Sample Data

Below are sample data, acquired using the experimental setup and procedure outlined in the Structured version of the lab activity, and answers to questions in the Data Analysis section.

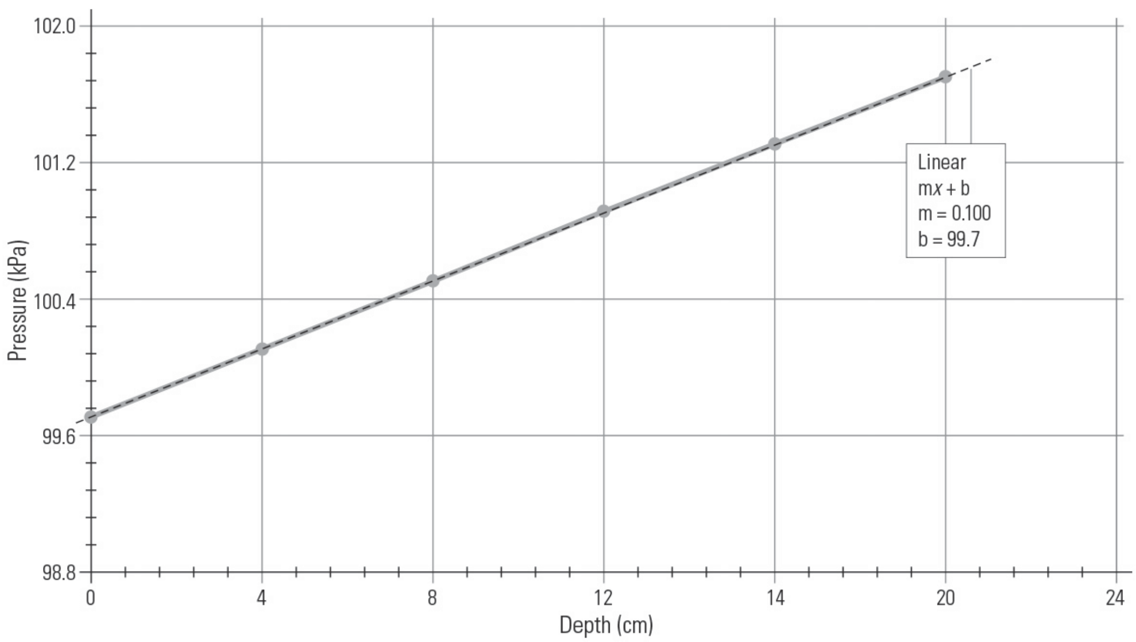
Data Analysis

Table 1: Pressure versus depth in a water column

Depth (cm)	Pressure (kPa)
0	99.71
4	100.10
8	100.50
12	100.91
16	101.31
20	101.70

1. Plot a graph of *pressure* versus *depth* in the blank Graph 1 axes. Be sure to label both axes with the correct scale and units.

Graph 1: Pressure versus depth in a water column



2. Draw a line of best fit through your data in Graph 1. Determine and record the equation of the line here:

Best fit line equation: $P = (0.100\ \text{kPa/cm})h + 99.7\ \text{kPa}$

Guided Inquiry Questions

Below are sample responses to the Guiding Questions found in the Guided Inquiry version of this lab activity.

1. Since the pressure sensor cannot be submerged in water, tubing attached to the pressure sensor must be placed in the water to take measurements. How long must your tubing be in order to take the necessary pressure measurements?

   The tubing must be at least as long as the height of the water reservoir so that measurements can be made at the bottom of the water reservoir. Because the tubing will likely curve when it is in the reservoir, the tubing should actually be slightly longer than the height of the reservoir.

2. Assuming the tubing is sealed air tight to the sensor, if you submerge the tube from the low-pressure sensor into the water reservoir, how will the pressure reading change as the end of the tube is submerged deeper into the water? Explain your answer.

   The pressure reading should increase as the end of the tube is submerged because the static pressure from the water, pushing on the air column, increases with depth.

3. If you submerge the entire length of tube into the water but the end of the tube remains exposed above the water's surface, what would the pressure read and why?

   The pressure sensor would read atmospheric pressure because the exposed end allows the air inside the tube to equilibrate with the atmospheric pressure above the water.

4. When the pressure inside the submerged tubing increases, what will happen to the volume of air inside the tubing, assuming that the tubing does not change shape, and how will this affect your depth measurements? Will you still measure depth at the end of the tubing?

   The volume of air will decrease because the increasing pressure causes the water level inside the tubing to rise. The depth will be measured from the water level inside the tube to the surface of the water because the air pressure in the tubing is balanced with the water pressure at this point.

Assessment Questions: Sample Responses

Sample responses to the Analysis and Synthesis questions found in each version of the lab activity:

Analysis Questions

1. Does a graph of pressure versus depth produce a linear relationship? If yes, what is the y-intercept of the relationship equal to, theoretically?

   A graph of pressure versus depth will produce a linear relationship. The y-intercept is equal to the atmospheric pressure.

2. Static pressure is related to depth according to the equation,

   $$P = P_0 + \rho g h$$

   where P is pressure, P_0 is the initial pressure, ρ is fluid density, g is acceleration due to gravity, and h is depth. From a linear graph relating pressure to depth, extrapolate a value for the density of the fluid in the reservoir (water). Show your work.

   $P = \rho g h$

   $\frac{P}{h} = \rho g$

   slope $= \rho g$; a typical result might be 10,000 Pa/m

   $\rho = \frac{\text{slope}}{g} = \frac{10{,}000 \text{ Pa/m}}{9.8 \text{ m/s}^2} = 1020 \text{ kg/m}^3$

3. If the theoretical value of the density of water is 1,000 kg/m^3, calculate the percent error between your experimental value and the actual value. Show your work.

$$\text{Percent error} = \left|\frac{\text{Actual} - \text{Experimental}}{\text{Actual}}\right| \times 100$$

Calculation using the typical result:

$$\text{Percent error} = \left|\frac{1000\ \text{kg/m}^3 - 1020\ \text{kg/m}^3}{1000\,\text{kg/m}^3}\right| \times 100 = 2.0\%$$

4. If you performed this same experiment using liquid iodine (density ≈ 4,900 kg/m^3) instead of water, how would a graph of pressure versus depth be different?

The graph would have a slope that is approximately 5 times as steep as water, but the *y*-intercept would remain the same.

Synthesis Questions

1. Imagine you are submerged in a submarine 1,066 m below the surface of the ocean. On this submarine is a round window made of glass. How thick would the glass need to be if 4 mm of glass is needed per 197.5 kPa pressure difference to prevent the glass from shattering? Assume ocean water has a density of 1,030 kg/m^3, and that the pressure inside the submarine is equal to atmospheric pressure.

$$P_{\text{water}} = \rho g h + P_0$$

$$P_{\text{submarine}} = P_0$$

$$\Delta P = P_{\text{water}} - P_{\text{submarine}} = \left(\rho g h + P_0\right) - P_0 = \rho g h$$

$$\Delta P = (1030\ \text{kg/m}^3)(9.8\ \text{m/s}^2)(1066\ \text{m}) = 1.076 \times 10^7\ \text{Pa}$$

$$\Delta P = \frac{1.076 \times 10^7\ \text{Pa}}{1.975 \times 10^5\ \text{Pa}} = 54.48$$

$54.48 \times 4\ \text{mm} = 217.9\ \text{mm}$ thick glass is needed

2. A group of marine biologist researchers have found a rare form of sea life that exists only at great depth in the ocean. If these researchers measured the gauge pressure at the depth these creatures live and found it to be 377 atm, at what depth in meters do these creatures live? Assume ocean water has a density of 1,030 kg/m^3.

$$\text{gauge pressure} = \Delta P = P - P_0 = \rho g h$$

$$h = \frac{\Delta P}{\rho g} = \frac{3.82 \times 10^7\ \text{Pa}}{(1030\ \text{kg/m}^3)(9.8\ \text{m/s}^2)} = 3784\ \text{m}$$

Extended Inquiry Suggestions

- Have the students investigate the relationship between pressure and fluid density. The students can measure pressure at the same fluid depth using different fluids. Here are some recommended fluids which are easy to obtain in local grocery or drug stores:
    - Cooking oil, 0.91 g/mL –0.92 g/mL
    - Isopropyl alcohol, 0.79 g/mL
    - Mineral oil, 0.80 g/mL
    - Glycerin, 1.26 g/mL
- The PASCO Barometer/Low Pressure sensor is sensitive enough to detect small changes in altitude. If you have access to a stairwell in a two-story building (or higher), the students can attempt to repeat this experiment using air as a fluid instead of water. Height measurements can be made by measuring the height of the steps in the stairwell.

NAME PERIOD DATE

1. HYDROSTATIC PRESSURE

STRUCTURED

Driving Question | Objective

How is static pressure related to depth in a column of water? Experimentally determine the mathematical relationship between static pressure and depth in a column of water.

Materials and Equipment

- Data collection system
- PASCO Barometer/Low Pressure Sensor[1]
- PASCO Sensor Extension Cable
- Quick connector[1]
- Tubing, 1/4" diameter, longer than 30-cm[1]
- Water reservoir, transparent, over 30 cm high
- Ruler
- Distilled water, to fill the reservoir 3/4 full

[1] www.pasco.com/ap24

PASCO Barometer/Low Pressure Sensor

Background

Anyone who has tried to swim to the bottom of a deep swimming pool has experienced the sensation of pressure on their body. The deeper you swim, the greater the pressure. So if you swim to twice the depth, would you feel twice the pressure? What is the mathematical relationship between the pressure on your body and the depth in the pool?

In this activity, you will measure the pressure at different depths using a pressure sensor to determine a mathematical relationship between pressure and depth.

Safety

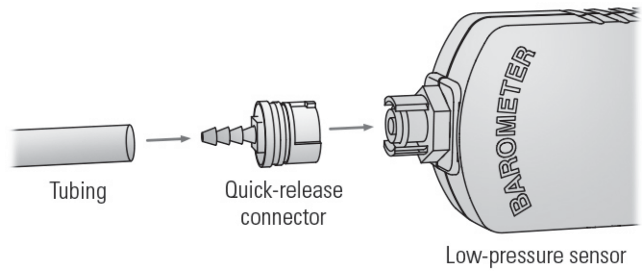
Follow this important safety precaution in addition to your regular classroom procedures:

- Make necessary arrangements to your workstation to avoid getting water on any electronic equipment.

Procedure

Set Up

1. Cut a length of 1/4" plastic tubing approximately as long as the water reservoir is deep, and connect the tubing to the valve on the low-pressure sensor using the corresponding barbed quick-snap tubing connector.



2. Connect the low-pressure sensor to the extension cable and connect the extension cable to the data collection system. Configure the data collection system to monitor data in a digits display.

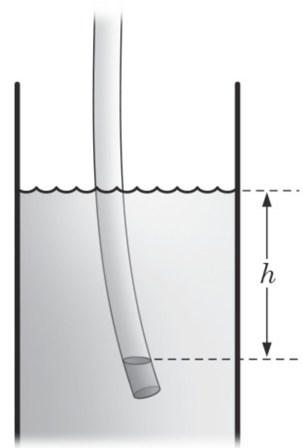
3. Fill the water reservoir approximately 3/4 full with distilled water.

Collect Data

4. Hold the low-pressure sensor and the attached tubing above the water level in the reservoir, and then record the first pressure measurement and corresponding depth (0 cm) in Table 1.

5. Submerge the open end of the tubing from the low-pressure sensor into the water, lowering the tubing end to a depth of 4 cm.

   NOTE: The tubing may not be straight, which is not a problem as long as the depth is measured at the point of the open end of the tubing.



6. Record the pressure P and depth h in Table 1.

   NOTE: At greater depths, a small volume of water may creep up the tubing as the air inside the tubing compresses. In this case, measure the depth h from the surface of the water to the water level inside the tubing.

7. Lower the tube into the water four additional centimeters.

8. Repeat the previous steps until you have recorded the pressure at six depths: 0 cm, 4 cm, 8 cm, 12 cm, 16 cm, and 20 cm.

9. Empty your water reservoir.

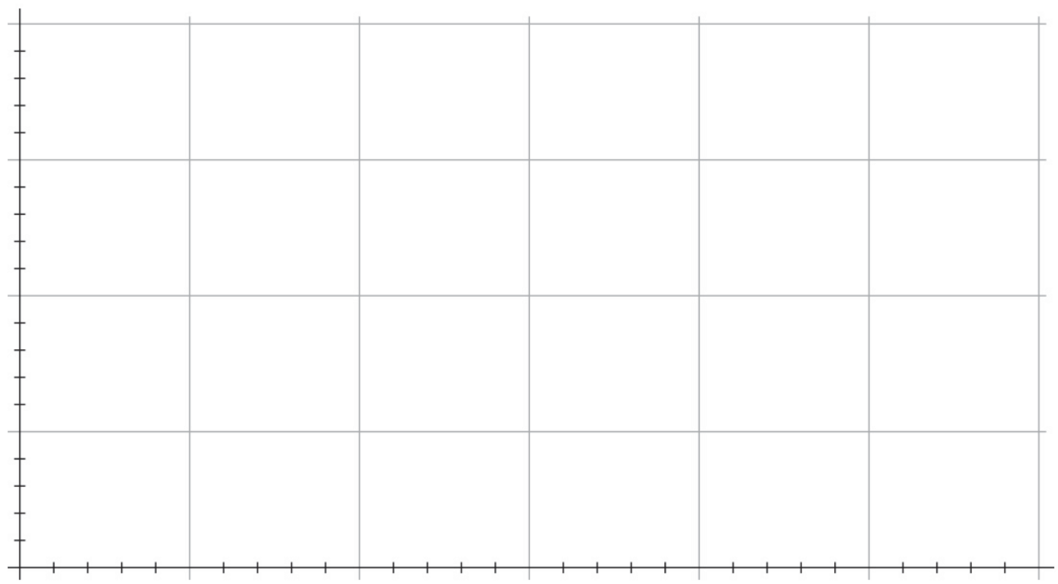
Data Analysis

Table 1: Pressure versus depth in a water column

Depth (cm)	Pressure (kPa)
0	
4	
8	
12	
16	
20	

1. Plot a graph of *pressure* versus *depth* in the blank Graph 1 axes. Be sure to label both axes with the correct scale and units.

Graph 1: Pressure versus depth in a water column



2. Draw a line of best fit through your data in Graph 1. Determine and record the equation of the line here:

   Best fit line equation: ______________________________

Analysis Questions

1. Does a graph of pressure versus depth produce a linear relationship? If yes, what is the y-intercept of the relationship equal to (theoretically)?

2. Static pressure is related to depth according to the equation,

$$P = P_0 + \rho g h$$

where P is pressure, P_0 is the initial pressure, ρ is fluid density, g is acceleration due to gravity, and h is depth. From a linear graph relating pressure to depth, extrapolate a value for the density of the fluid in the reservoir (water). Show your work.

3. If the theoretical value of the density of water is 1,000 kg/m^3, calculate the percent error between your experimental value and the actual value. Show your work.

$$\text{Percent error} = \left|\frac{\text{Actual} - \text{Experimental}}{\text{Actual}}\right| \times 100$$

4. If you performed this same experiment using liquid iodine (density ≈ 4,900 kg/m^3) instead of water, how would a graph of pressure versus depth be different?

Synthesis Questions

1. Imagine you are submerged in a submarine 1,066 m below the surface of the ocean. On this submarine is a round window made of glass. How thick would the glass need to be if 4 mm of glass is needed per 197.5 kPa pressure difference to prevent the glass from shattering? Assume ocean water has a density of 1,030 kg/m^3, and that the pressure inside the submarine is equal to atmospheric pressure.

2. A group of marine biologist researchers have found a rare form of sea life that exists only at great depth in the ocean. If these researchers measured the gauge pressure at the depth these creatures live and found it to be 377 atm, at what depth in meters do these creatures live? Assume ocean water has a density of 1,030 kg/m^3.