APP1 Equipment List*

Equipment	What is it Used For?	How Does It Work?	Notes and Limitations
Meter stick	measuring **length** in meters.	How to Measure using a Meter Stick	• measurements <1 mm must be estimated, that is between the marks (uncertainty of ±0.001 m at least) • must be moved to measure larger than 100 cm/1 meter • difficult to use with moving objects • use measuring tape for larger distances • must designate TWO positions to measure a length, distance, or displacement
Balance	measuring the gravitational **mass** of an object in grams, kilograms, etc.	How to Use a Triple Beam Balance	• only measures objects that can be placed on the balance • all balances have an uncertainty of about ± the smallest value • usually okay to use "known masses" and not measure them on a balance
Spring Scale	measures the **gravitational force** on a hanging object (usually in newtons) or measures pulling forces applied to the scale	Difference Between a Balance and a Scale	• has an uncertainty of plus/minus smallest value on scale • objects must hang from the hook in a gravitational field to measure gravitational force • not useful for forces that change rapidly (as in impulse experiments)
Stopwatch	measures the elapsed **time or time interval** an event takes in seconds.	How to Read and Use a Stopwatch	• rel. large uncertainty of plus/minus 0.1 s or even more • many events in lab take place in 1.0 s or less, making stopwatch data unreliable • compensate for unreliability by measuring events multiple times and dividing by number of events
Motion Detector	continually measures the **position** of an object relative to the detector. Motion detectors are often connected to graphical software to generate **position-time, velocity-time, and acceleration-time graphs.**	Using a Motion Detector	• object must ONLY move in a line back and forth in front of the detector • object must be farther than 20 cm away and less than 8 m away • nothing else can be between the object and what it is measuring • object must be reflective (soft, squishy things don't work well) • for experiment questions, you MUST EXPLAIN the placement of the motion detector(s) and what SPECIFIC QUANTITIES they will measure (a

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			diagram is best; this may require multiple motion detectors in one experiment)
Tracks & Carts	Tracks provide a **low friction horizontal or inclined surface** to study motion of carts. Carts have **low friction wheels** and can move freely along a track. This setup is usually supplemented by a motion detector.	[Track and Cart System Overview]	• practical low-friction object for many experiments • carts of known mass may be used, but if objects are attached, mass should be measured on balance • only moves in a straight line • include fan attachment or use mass suspended from pulley to apply constant force
Force Sensor	Measures the amount of **force** applied to the sensor in newtons. Can measure pushes (with a bumper) and pulls (with a hook). May be used handheld, attached to a stand, attached to a cart.	[Dual Range Force Sensor]	• has an uncertainty related to its range (available with different ranges from very small to very large) • must connected to a computer to produce graphs of force and time (useful for impulse) • sample rate must be increased to avoid missing brief events
Pulley	**Redirects** the tension force in a string/rope/cable/etc. Pulleys are usually considered **massless and frictionless** so the tension can be constant over the pulley.	[Pulley Redirecting Force]	• can be ignored if small, light, and low internal friction • if large, heavy, or has friction, its inertia (and its frictional torque) will affect experimental results
Video analysis	Take slow-motion ("high-speed") video of a moving object with an object or objects of known size in the image and examine the video to find **position**, **velocity**, and **acceleration** data	[Capturing Position-Time Data from a Video Clip]	• works well if light is good, background contrasts, object is easily visible • camera must not move or zoom • camera must remain perpendicular to motion
Rotary Motion Sensor	Measures **angular position**, **velocity**, and **acceleration**, typically by a string passing over the pulley on the sensor (radians or degrees per second)	[Vernier Rotary Motion Sensor]	• can be used in linear mode • relatively low uncertainty (± mm in linear mode)
Photogate	Measures the **time** that the photogate's infrared beam is interrupted as an object passes through the photogate.	[Things You Can Do With a Photogate]	• object must pass through the photogate perpendicular to it • very little uncertainty (milliseconds) • with two photogates, you can record the precise beginning and end of a motion • there are attachments for photogates that allow recordings of velocity and acceleration (I only recommend using these in rare circumstances)

*In answering AP1 Experimental Free-Response Questions, I would recommend sticking with the simple and familiar where you see a way to do that. A meter stick, stopwatch, and balance can go a long way.

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List of useful measurement techniques:

Need to find	**How to find it**
final speed of a dropped object (at the bottom of its drop)	• Use meterstick to measure initial height • Solve conservation of energy $\frac{1}{2}mv_f^{\ 2} = mgh_i$
initial speed of a bouncing object (at the start of its upward motion)	• Use meterstick to measure final height • Solve conservation of energy $mgh_f = \frac{1}{2}mv_i^{\ 2}$

velocity, momentum, kinetic energy, before or after a collision	• Option 1: use meterstick and stopwatch, divide to find constant velocity of all objects before and after collision
	• Option 2: Use TWO motion detectors at opposite ends of track to record velocity of ALL objects before and after collision
	• Calculate momentum and kinetic energies from velocities and mass
	• Solve conservation of momentum (and possibly conservation of kinetic energy)
	  ○ Totally Inelastic (one final velocity) $m_A v_A + m_B v_B = (m_A + m_B)v'$
	  ○ Elastic (two final velocities, kinetic energy constant) or inelastic (two final velocities, kinetic energy decreased)
	  ○ $m_A v_A + m_B v_B = m_A v_A' + m_B v_B'$

acceleration of any object that starts from rest	• Use a meterstick to measure distance, stopwatch to record time • Calculate using $\Delta x = \frac{1}{2}a_x t^2$
time of flight for any dropped or horizontally-launched object	• Use a meterstick to measure height • Calculate using $\Delta y = \frac{1}{2}gt^2$
spring constant	• Attach known masses to vertical spring • Use meterstick to measure stretch • Calculate gravitational force applied to spring • Plot F vs. stretch, find slope from best-fit • slope is spring constant
period or frequency of a rotating or oscillating object	• Use stopwatch to record multiple cycles (10 is a good amount) • Divide total time by number of cycles to determine period • If frequency is needed, $f = \frac{1}{T}$

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maximum speed of a pendulum bob	• Calculate from initial gravitational potential energy and kinetic energy using $\frac{1}{2}mv_f^{\ 2} = mgL(1 - \cos\theta)$
gravitational force	measure mass with balance calculate using $F_g = mg$

Tips for answering Experimental Questions

- Look at the AP Equation table to remind yourself of an equation or equation that relates to the experimental question
- Draw a diagram to show where you'd place measuring tools or measured quantities.
- You may use "known masses," "carts of known mass" or springs of "known spring constant." If you add other objects to the known masses, you better have a balance.
- Kinetic energy, potential energy, momentum and many other quantities can't be directly measured. You must explain how you'd calculate them from measured quantities.
- Specify that you will measure different trials, producing different ordered pairs (vary your independent variable)
- Specify that you will repeat individual measurements and average the results to reduce the effects of uncertainty
- Plot a graph of the independent variable vs. the dependent variable
- Linearize a non-linear graph of the independent variable vs. the dependent variable
- Determine the slope from the best-fit line, not the points
- Use the meaning (physical significance) of the slope or the intercept to answer questions

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