UNIT 2 | AP Physics C/ECE1401 • ECE1201 • Honors Physics

Student workbook | Forces & Translational Dynamics

Name: _____ Section: _____ Date: _____

Circle your path: AP Physics C/ECE1401 | ECE1201 | Honors Physics

This workbook accompanies the shared Unit 2 website. The physical laboratory write-ups are online. Complete only your assigned course sections and investigations.

Guiding questions

- How do forces determine whether velocity changes?
- How do we represent interactions with free-body diagrams and mathematical models?
- How can uncertainty and experimental evidence challenge a model?

Lesson road map

Lesson	Common learning target	Course extension
2.1–2.2	Interactions, FBDs, Newton's laws	Symbolic equations in all courses
2.3–2.4	Friction, inclines, connected systems	More complex coupled systems in ECE1201 / 1401
2.5	Spring calibration, uncertainty	Variable-force treatment reserved for 1401
2.6	Circular motion and gravitation	Honors returns to gravity in later unit
2.7	—	Drag / separable ODEs: 1401 only

STRIDES organization

Subject • Topic • Rules • Illustrations • Definitions • Example • Steps. Use the blank spaces to add rules and diagrams during instruction.

What do you already know about force, acceleration, and uncertainty?

Historical inquiry | Newton, evidence, and authority

Driving question: How can the success of mathematical laws of nature contribute to a broader culture of reason without itself proving any theory of political rights?

Short source excerpts and context

Newton, Principia (1687): “Every body perseveres in its state of rest”; “To every action there is always opposed an equal reaction.”

Newton, General Scholium (added 1713): “I frame no hypotheses.” The later text also discussed divine order.

Tillotson: William M. Spellman describes a religious thinker who defended reason within Protestant faith, not a straightforward rejection of religion.

Historical context: Newton also resisted King James II’s demand that Cambridge bypass university rules. That political dispute should not be confused with his experiments.

1. Which of Newton’s assertions can be tested experimentally? Propose a concrete demonstration.

2. How could a religious leader defend reasoned inquiry without calling for secular government?

3. Write a claim connecting scientific method and Enlightenment reasoning, then state an important limit to that claim.

Source paths: Library of Congress, Principia (1687); Newton Project; General Scholium (1713); Spellman (1987), Anglican and Episcopal History 56(4).

The force primer | From interaction to model

STRIDES note cues

Subject: Force and translational dynamics. Topic: Defining forces and identifying an isolated system.

Rules: Newton I, II, III; $\Sigma F(x) = m\,a(x)$; $\Sigma F(y) = m\,a(y)$; gravitational weight $W = mg$.

Illustrations: Free-body diagrams include only forces acting on the isolated object. Definitions: interaction, external force, net force, equilibrium, normal, tension, friction.

Example: A box remains motionless with a 12 N push right and 12 N static friction left. Both individual forces are nonzero, yet the net horizontal force is zero.

Steps: (1) choose system; (2) identify force sources; (3) draw force vectors; (4) choose axes; (5) write component equations; (6) solve and interpret.

4. Define force and net force in your own words, including vector direction.

5. Two distinct objects interact. Explain why third-law partners must appear on different FBDs.

6. Draw separate diagrams for a book resting on a table and for the table. Label what exerts each force.

Book free-body diagram	Table free-body diagram

Worked-model practice I | Elevator and force vectors

Use the full worked examples on the website for comparison after completing your diagrams and equations.

A. Elevator scale

A 72 kg person rides an elevator accelerating downward at 1.25 m/s². Find the scale reading. Compare with constant-speed motion.

Isolated body and two force sources:

Vertical net-force equation (choose positive direction):

Calculated scale reading and explanation:

B. Missing third force

Three cords hold a ring stationary. F1 = (+14,0) N; F2 = (−6,+8) N. Find F3, its magnitude, and its direction.

Make a force-vector diagram and show component balance.

Find the missing components, magnitude, quadrant and angle.

Worked-model practice II | Circular motion and tension

A. Friction on a circular turn

A go-kart takes a level circular turn of radius 24 m. The available coefficient of static friction is 0.65. Determine the maximum speed using only Newton’s laws.

Side-view forces and top-view radial direction (sketch both):

Show vertical equilibrium and inward radial equation; solve symbolically before using numbers.

Why does mass cancel, and why is static friction not always equal to μsN?

B. Conical-pendulum tension

A 0.60 kg bob on a 2.0 m cord moves at a constant angle of 30° from the vertical. Determine tension and horizontal speed.

Sketch tension, weight, vertical balance, and radial equation.

Use r = L sin θ and evaluate T and v.

1401 ONLY | Derive motion from nonuniform force

Honors Physics and ECE1201 students do not need this page. Use Newton’s second law and calculus, using Newton’s second law and previous kinematics calculus only.

A. Time-dependent propulsion

A 2.00 kg cart starts with v(0)=1.0 m/s at x(0)=0. Its net horizontal force is F(t)=(4.0 + 2.0t) N during the first 3.0 s (t in seconds).

Write a(t) from m dv/dt = F(t) and check its units.

Integrate to obtain v(t), including the initial condition.

Integrate to obtain x(t). Evaluate v(3) and x(3).

B. Resistance

For downward motion with a linear resistive force, m dv/dt = mg − bv. Show where the terminal speed comes from before solving the differential equation.

Separate variables and solve for v(t) given v(0)=0.

Check the physical limiting cases t=0 and t→∞.

Modeling studio data | Sliders should tell a physical story

Record one variable changed at a time. The revised diagrams scale force vectors as relevant quantities vary and distinguish force from acceleration.

Stacked blocks

Select “floor on A.” Increase only the top mass. Which vectors increase? Why does the supported mass change?

Select “B on C.” Change only the bottom block mass. Why should that support force not change?

Force-angle demonstration

Hold force at 20 N and angle at 90°. Change mass from 1 kg to 5 kg. Why does the force arrow stay fixed while the acceleration arrow changes?

Maximum incline push

Hold mass and angle fixed. Increase available push. What is the limiting angle, and how do force arrows convey the comparison?

Experimental connection

In the Newton’s second-law lab, test whether acceleration changes when net force is held constant but mass increases. In the critical-angle lab, explain why changing mass ideally does not change μs.

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2.1 | Interaction forces & STRIDES notes

Subject: Mechanics Topic: Forces and interaction diagrams

Rules: Write the names of relevant Newton's laws and force-modeling rules. Add conditions under which each applies.

Rules to add during class

Definitions: Interaction, force, net force, inertial mass, gravitational mass, normal force, tension, friction, external force.

Define at least four terms precisely

Illustration and free-body diagram

Draw a separate free-body diagram for a book resting on a desk. Include the objects responsible for the forces. Draw the interaction partners in a second diagram.

System diagram and separate free-body diagrams

Example: A small sled is pulled horizontally at constant speed. Explain whether the applied force must be zero.

Claim, supporting force relation, and explanation

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2.2 | Newton’s laws and mathematical modeling

Rules: Identify the force acting on the chosen object. Choose positive axes and show vector components. Start with symbolic equations, then insert numerical values.

$$\Sigma F_x = ma_x \bullet \Sigma F_y = ma_y$$

Reason before calculating

1. A 1.6 kg glider experiences a horizontal net force of 3.2 N. Predict its acceleration. Then explain how that acceleration changes if the glider mass triples while the same net force acts.

Free-body diagram, equation, result and explanation

2. Two students push opposite sides of a wheeled box with forces of 34 N and 26 N. The floor supplies an opposing resistive force of 3 N. Determine the acceleration if the box mass is 5 kg.

Clearly state positive direction and which forces oppose motion

STRIDES steps

List the five steps your class will use before entering numbers into an equation.

Steps for modeling motion

Force models: think before solving

When a force acts, the velocity vector changes in the direction of the net force. Do not assume that every force immediately increases speed.

Five-step routine

1. Box or name the system and identify its interaction partners.
2. Draw forces acting ON that system only. Name who exerts each force.
3. Choose positive axes; calculate components only after the axes are set.
4. Write a separate net-force equation along each axis.
5. Check units, sign, limiting conditions, and assumptions.

Original conceptual inquiry

A puck moves rightward on level ice. At one instant its net force points straight upward on the page. What changes immediately: speed, direction, both, or neither? Justify using vector components.

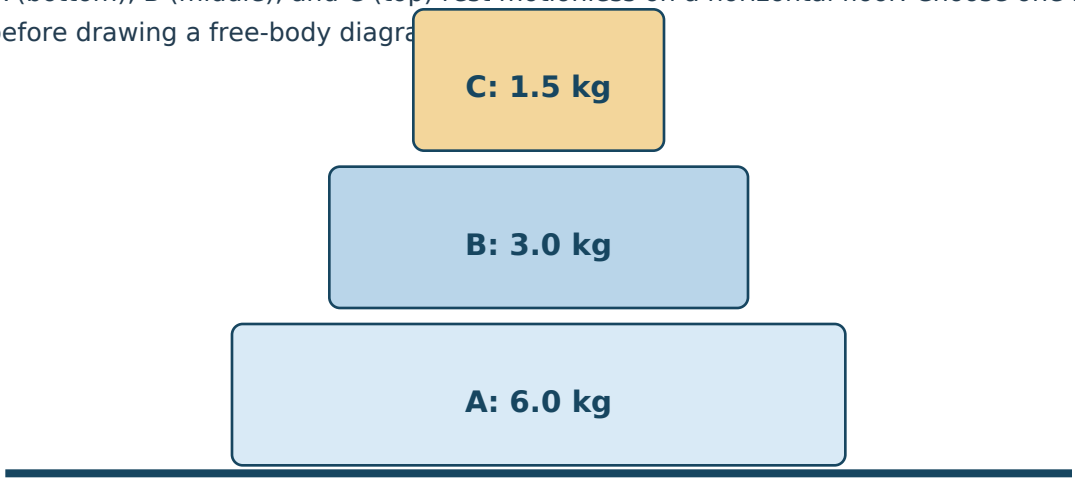
Sketch: velocity, force, and their parallel/perpendicular components

Now imagine the upward force stays fixed in the same laboratory direction. Is it still perpendicular to the velocity a moment later? Explain why this matters.

Explanation + contrast with uniform circular motion

Normal forces in a stack of objects

Three blocks A (bottom), B (middle), and C (top) rest motionless on a horizontal floor. Choose one block as your system before drawing a free-body diagra



1. Free-body diagrams

Draw a separate FBD for A, B, and C. Label each contact force with both objects (e.g., B on C).

Separate FBD sketches: A | B | C

2. Derive the supporting normal forces

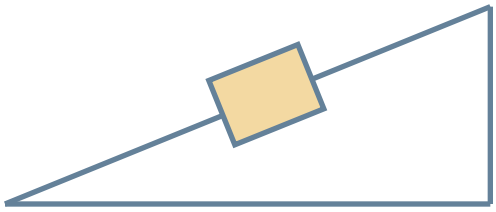
Write symbolic vertical equations, then compute (a) B on C, (b) A on B, and (c) floor on A. Explain why normal force differs at each interface.

Net-force equations and numerical normal forces

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2.3 | Inclines and the onset of friction

Illustration: Draw complete forces and resolve the weight parallel/perpendicular to the ramp. No friction is shown until its direction is justified.



Incline angle θ

Add force arrows:

- gravitational force
- normal force
- friction (if appropriate)

Show parallel axes.

$N = mg\cos\theta$ $F_{(gravity,\ parallel)} = mg\sin\theta$

Definitions: Static friction can take any magnitude from 0 up to $\mu_s N$. Kinetic friction acts during sliding and its idealized magnitude is $\mu_k N$.

A 4.0 kg block is placed on a 28° incline, $\mu_s = 0.40$, $\mu_k = 0.24$. Predict if it begins sliding. Only if it moves, determine its initial acceleration.

FBD → critical-friction test → net force equation → answer

Explaining the model

Does increasing the mass alone change the idealized critical angle? Justify mathematically and physically.

Explanation with the relationship $\tan\theta_{(c)} = \mu_s$

Find the limiting angle - then test it

A 340 kg supply sled is pushed parallel to a smooth, frictionless ramp. The motor can supply at most 1650 N uphill. Determine the steepest slope it can climb without slowing, and predict its acceleration on a 20° ramp at maximum push.

Your starting assumptions

Object and coordinate axes: _____

Forces acting on the sled: _____

What does "without slowing" tell you about the limiting acceleration? _____

Free-body diagram and parallel/perpendicular components

Symbolic model, theta_max, acceleration at 20°, and unit check

Limiting case: what happens as the angle approaches 0°? What if the motor can exert more force than the total weight? Explain why the normal is not necessarily mg.

Conceptual explanation

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2.4 | Connected systems, tension & equilibrium

An ideal string and pulley impose equal-magnitude motion along the rope; a physical apparatus may depart from that ideal. Draw a separate FBD for every object.

Scenario: A 2.5 kg mass and a 3.5 kg mass hang from opposite ends of a massless string over a frictionless pulley. Find the acceleration and tension.

Two free-body diagrams and two independent force equations

A platform accelerates upward at 1.5 m/s². A 12 kg crate remains at rest relative to the platform. Determine the normal force on the crate and explain why N ≠ mg.

FBD, signed y-axis equation and result

Model limitation: Name one plausible reason a real pulley system gives a smaller acceleration than the ideal model.

Reasoned experimental limitation

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2.5 | Spring calibration & measurement uncertainty

Spring calibration is shared across all three courses. Treat F versus x as a linear experimental relationship over the tested range. More advanced variable-force work belongs to 1401.

$$F_{spring} = -kx \quad |F| = kx \quad k \text{ in N/m}$$

A spring exerts a force magnitude of 1.80 N when extended 0.060 m. Find k and predict the magnitude at 0.085 m. Explain why a small preload or incorrect zero-length reading biases the result.

One worked calibration and one systematic-error explanation

Designing a spring lab

Trial	Mass m (kg)	Extension x (m)
1		
2		
3		
4		
5		

Determine k from the slope of an F-versus-extension graph. Explain how measurement uncertainty in m and x affects the reported k.

Uncertainty method and sources

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2.6 | Curved motion & gravitational force

Uniform circular motion requires inward acceleration, but it does not require a special additional “centripetal force.” Identify the ordinary force(s) that supply the inward net force.

$$a^c = v^2/r \quad \Sigma F_{radial} = mv^2/r$$

A 0.30 kg ball moves in a horizontal circle of radius 0.80 m at speed 2.4 m/s. Find the inward net force magnitude. Sketch the direction of velocity and acceleration at one instant.

Plan-view sketch and net inward force

A satellite in a circular orbit at distance r from Earth's center experiences a gravitational force. Show symbolically how to find the orbital speed assuming gravity is the only radial force.

Equation using $F = GMm/r^2$ and mv^2/r; simplify

Honors pathway: Your teacher may revisit gravitational models in the next mechanics unit. ECE1201 and 1401: Include symbolic justification and assumptions.

One misconception about circular motion and its correction

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Course practice | Honors Physics

Honors only. Every answer needs a diagram or explanation as well as numerical work. These are original practice questions, not archived assessment items.

1. A wagon with mass 8.0 kg is pulled horizontally by a 28 N force. Resistive force is 4.0 N. Find net force and acceleration; explain the direction of motion change.

FBD → net force → acceleration

2. A shoe slides down a 24° ramp at constant speed. Find the coefficient of kinetic friction in the idealized model. Explain why the mass cancels.

Force components and kinetic-friction equation

3. A student measures spring extension to the nearest millimeter. Explain the difference between a measured value, the spring constant, random uncertainty and systematic bias.

Definitions, physical examples, and an improved method

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Course practice | ECE1201

ECE1201 only. Include modeled assumptions, intermediate equations, significant figures, units, and a short error analysis.

1. A 4.5 kg crate on a 33° rough incline slides down with kinetic coefficient 0.18. Determine its acceleration. If an upward applied force of 9.0 N is added along the plane, predict the new acceleration while the crate continues downward.

Two scenarios, complete FBD and component equations

2. A 2.0 kg cart and a 0.75 kg hanging mass are connected by an ideal rope and pulley; cart friction is measured as 1.8 N. Find acceleration and tension.

Two FBDs and systematic solution

3. Design a direct experiment to test whether total acceleration is proportional to measured net force; specify control variables, a data reduction method, and how uncertainty will be quantified.

Procedure rationale and uncertainty plan

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Course practice | AP Physics C/ECE1401

1401 only. Derive equations before computing; indicate when a differential equation becomes necessary.

1. A glider of mass m experiences an applied horizontal force F and linear resistive force bv in the opposite direction from motion. Write Newton’s second law as an ODE; find the terminal speed and time constant.

FBD, ODE, terminal-speed argument, dimensional check

2. For a block sliding down an incline with kinetic friction, derive an expression for acceleration in terms of θ, μ_k and g. Use your expression to explain mass independence.

General model, not only numeric substitution

3. A hanging two-mass system includes an uncertain measured mass and uncertain resisting force. Identify derivatives needed to propagate uncertainty into the predicted acceleration.

Partial derivatives and sensitivity interpretation

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AP Physics C/ECE1401 only | Drag and separable equations

The calculus pathway goes beyond a force diagram into modeling how velocity changes over time. Choose downward as positive and assume the object moves downward.

$$m\,dv/dt = mg - bv \text{ (linear drag)}$$

1. Separate variables without guessing a solution. Integrate both sides and apply release from rest, $v(0) = 0$.

Separation → substitution → integration → initial condition

2. Derive the terminal velocity by setting $dv/dt = 0$. Explain the difference between terminal velocity and a constant applied force.

Physical meaning of the limit

3. Quadratic drag: $m\,dv/dt = mg - cv^2$. Explain how video acceleration data could distinguish this from a linear-drag law. Include a fit-quality criterion and one measurement limitation.

Data-model choice, not a memorized formula

Linear drag - a physical differential equation

A cart moves down a frictionless incline of angle theta. Gravity pulls down the slope, and a resistive force of magnitude bv acts opposite the velocity. Take downhill as positive; cart begins at rest.

Stage 1. Start with a force diagram and Newton II

Write all forces and their directions. Derive the differential equation for velocity. What are the dimensions of b?

FBD, net force equation, and dimensional analysis

Stage 2. Separate and integrate

Set dv/dt = g sin(theta) - (b/m)v. Separate variables, integrate, and use the initial condition v(0) = 0.

All integration steps and the initial condition

Stage 3. Interpret the model

Determine terminal speed vT, time constant tau, and test t = 0 and t tending to infinity. Does the model approach v = g sin(theta)t as b tends to zero?

Limits, graph shape, and physical meaning

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Laboratory A | Newton’s second law

Course: all three. Core question: Can measured acceleration be predicted using the net force and the mass of the accelerated system?

Apparatus: cart/track or equivalent, measurable applied force, meter scale, stopwatch, motion sensor or video when available. Student groups choose a reproducible and safe arrangement.

Pre-lab controls

Clearly state which mass is accelerating, which force is the net force, whether the object begins at rest, and how friction may affect the result.

Research question, initial prediction, and controls

Condition	Net force F (N)	Distance d (m)	Time t (s)
1			
2			
3			
4			
5			

$$a = 2d/t^2 \; ; \; u_a/a \approx \sqrt{[(u_d/d)^2 + (2u_t/t)^2]}$$

From the web report calculate acceleration, compare F and ma, and discuss model versus measured uncertainty.

Explain one source of systematic error and a concrete improvement

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Laboratory B | Critical-angle friction

Course: all three. Protocol: raise a flat rigid surface until a block just begins sliding, record the angle, and repeat ten times. Select a controlled comparison of mass or surface type.

Trial	Measured critical angle θ (°)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

$$\mu_s = \tan(\text{average } \theta) \; ; \; u\mu \approx (1 + \mu_s^2)u\theta(\text{radians})$$

Calculate average angle, sample standard deviation and uncertainty of the mean. Be explicit about measurement resolution, release technique, and any instrument bias.

Show one uncertainty computation; explain mass cancellation

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Laboratory C | Hooke’s law, stiffness & uncertainty

Course: all three. Core question: Is spring restoring-force magnitude proportional to extension over the tested range?

Measure unloaded length; add known masses one at a time, measure extension and remove each mass safely. Estimate u_m and u_x from apparatus resolution and procedural variation.

Trial	Mass (kg)	Extension x (m)
1		
2		
3		
4		
5		
6		

$$k = mg/x \; ; \; u_k/k \approx \sqrt{[(u_m/m)^2 + (u_x/x)^2]}$$

Compare a best-fit slope to individually calculated stiffness values, explain whether the linear model is appropriate, and distinguish the spread from a systematic zero-offset.

Data reduction, uncertainty interpretation, and improvement

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Laboratory D | Drag & variable force (1401 ONLY)

This entire page is for AP Physics C/ECE1401 only. ECE1201 and Honors should skip it.

Use motion-sensor or video-based falling-object data to estimate the instantaneous downward speed and acceleration. With downward positive, calculate measured drag force from Newton's second law.

$F_{drag} = m(g - a)$; compare $b \cdot v$ and $c \cdot v^2$

Sample	v downward (m/s)	a downward (m/s²)
1		
2		
3		
4		
5		
6		
7		

Fit both models with the same measured dataset. Compare fit residuals and physical reasonableness. Discuss uncertainty introduced when estimating acceleration from noisy position data.

Chosen model, evidence from residuals, and a limitation

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Projectile launcher | Unit 2 design checkpoint

Your larger projectile design project is divided across units. This checkpoint focuses only on the force model and spring characterization. The energy transfer and full range prediction are developed later.

Deliverable 1: annotate and analyze your mechanism

Physical design, launch force diagram and post-release diagram

Deliverable 2: establish what you can measure now

Quantity	How will you measure it?	Expected uncertainty / control
Spring displacement x		
Spring stiffness k		
Contact/guide friction		
Projectile mass		

Deliverable 3: peer design review

One specific criticism → one physical revision → one plan to evaluate it

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Unit 2 synthesis | Evidence and skills check

Complete before the unit assessment. Do not simply list formulas; indicate what each model assumes and what evidence would test it.

Required independent skills

- Draw an accurate FBD for a single object and for two interacting objects.
- Resolve vectors on an incline and distinguish static from kinetic friction.
- Write separate force equations for connected systems and identify common acceleration constraints.
- Explain why circular motion has inward acceleration but no new “centripetal force.”
- Report measured uncertainty and discriminate random spread from systematic bias.
- 1401 only: derive or separate a velocity-dependent differential equation and judge drag-model fit.

Short reflection

What is one result from the unit that your first intuition would not have predicted? Support your answer with a diagram or observed data.

Claim → data or equation → why your thinking changed

Lab report final check

☐ Physical measurements documented ☐ Units and axes ☐ Models/assumptions ☐ Uncertainty
☐ Bias/revision ☐ Exported PDF attached