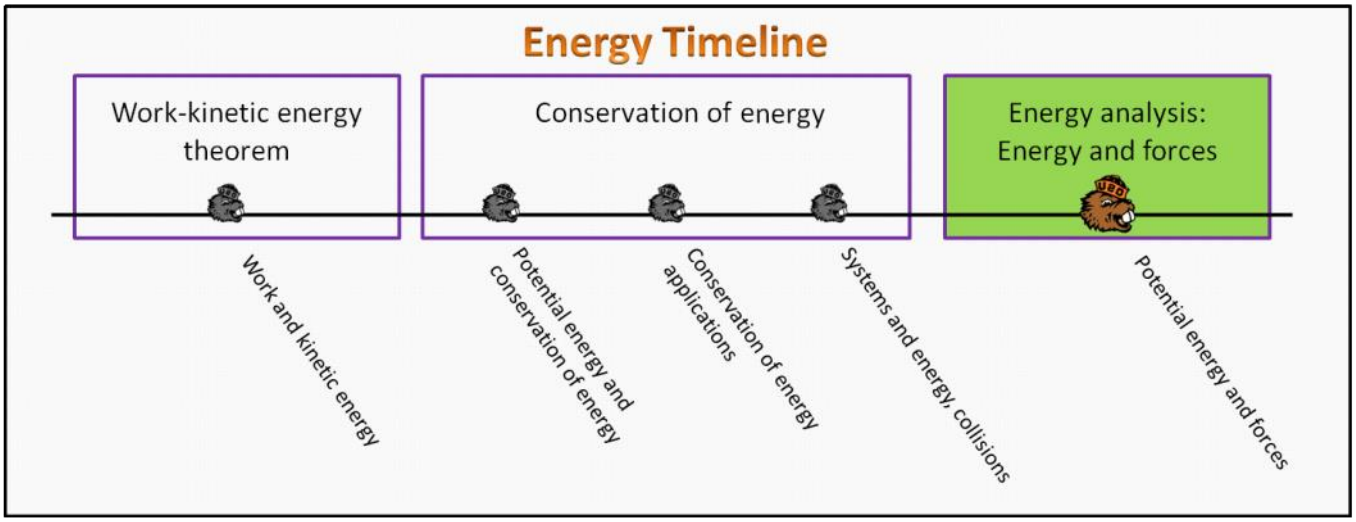
Energy analysis: Energy and Forces
Foundation Stage (EA.2.L1)

lecture 1
Potential energy and forces



Textbook Chapters (* Calculus version)

- **BoxSand** :: KC videos (N/A)
- **Giancoli** (Physics Principles with Applications 7th) :: N/A
- **Knight** (College Physics : A strategic approach 3rd) :: N/A
- ***Knight** (Physics for Scientists and Engineers 4th) :: 10.6

Warm up

EA.2.L1-1:

Description: Open ended question about energy.

Learning Objectives: [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

Problem Statement: What is energy?

Feynman's analogy for energy (http://fliphysics.com/wp-content/uploads/feynman_coe.pdf)

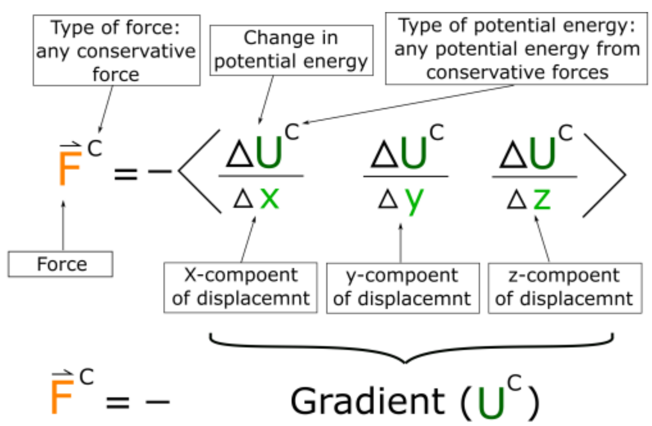
Selected Learning Objectives

1. Determine the direction of force for 1-D motion by analyzing the solve of a potential energy function vs position.
2. Identify locations of equilibrium, both stable and unstable, on a plot of potential energy vs position.
3. Identify forbidden regions on a potential energy vs position graph.
4. Determine the binding energy to overcome a local potential energy barrier.
5. Determine the net energy released/absorbed when a system overcomes a local potential energy barrier.
6. Extract potential energy information from a topological map.
7. Identify energy transformation on the macroscopic scale (e.g. earth + sun).
8. Construct a potential energy function given short and long range behaviors for a bound system.

Key Terms

- Gradient
- Equilibrium
- Stable equilibrium
- Unstable equilibrium
- Potential energy well
- Forbidden region
- Potential energy barrier
- Topological map
- Light energy
- Molecular binding
- Nuclear binding
- Nuclear energy

Key Equations



$$\vec{F}^C = -\left\langle \frac{\Delta U^C}{\Delta x}\ \frac{\Delta U^C}{\Delta y}\ \frac{\Delta U^C}{\Delta z} \right\rangle$$

$$\vec{F}^C = -\ \text{Gradient}\ (U^C)$$

In words: The force (from any conservative force) is equal to the negative gradient of potential energy due to the conservative force. The gradient is defined as the vector created by taking the change in potential energy divided by each compoenet of displacement respectively. Thus the gradient can be considered as a "three-dimensional slope".

Key Concepts

- The force along one direction can be found by taking the negative slope of a potential energy function vs position along the direction. If there are more than 1 directions, then multiple plots of energy vs direction must be constructed; finding the slope of each plot is then referred to as finding the gradient, basically a 3-D slope. Each of the slopes represent the corresponding x, y, and z components of force.
- A potential energy well is a concave up shape on a potential energy plot vs position.
- Equilibrium (mechanical equilibrium) is defined as the scenario when the net force is zero.
- A stable equilibrium is an equilibrium location where the net force always points towards it if displaced from the equilibrium location. Thus, stable equilibrium locations are at the bottom of a concave up part of a potential energy plot vs position.
- An unstable equilibrium is an equilibrium location where the net force always diverges (point away) if displaced from the equilibrium location. Thus, unstable equilibrium locations are at the peak of a concave down part of a potential energy plot vs position.
- An isolated system can never have more energy than the total energy is has, thus you cannot find the system in regions where the energy is larger than the total energy on a potential energy vs position plot. Forbidden regions refer to the range of energy values and position values that are in regions of energy that are larger than the total energy of the isolated system.

- A potential energy barrier is the energy needed to move from the bottom of one potential energy well to another potential energy well.
- Topological maps show lines of constant height above some reference height (usually sea level). Recall that gravitational potential energy follows the topology of the surface, thus the lines on a topological map are analogous to lines of equal gravitational potential energy. Recall, gravitational potential energy is equal to **m g y**, so if you multiple the height on a topological map by **m g**, then you get the gravitational potential energy.
- Light is a wave that carries energy from one location to another.

Act I: General potential energies

Questions

EA.2.L1-2:

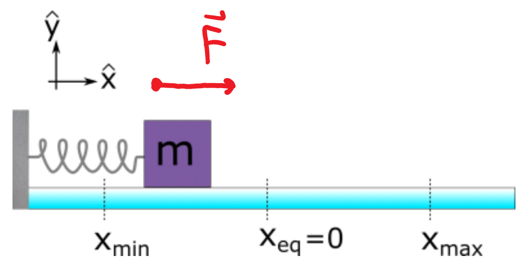
Description: Determine direction of force given a snapshot of a mass on a spring. Match the correct potential energy diagram for a spring mass system. (2 minutes + 2 minutes)

Learning Objectives: [1]

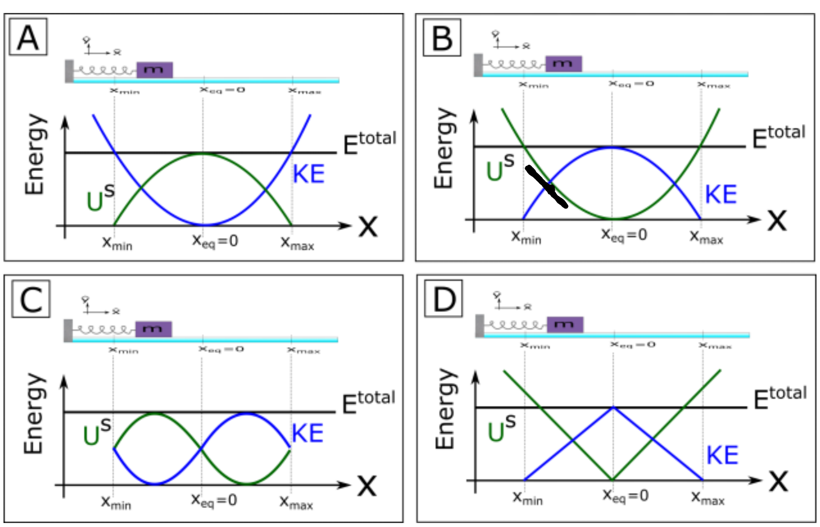
Problem Statement: Consider an ideal spring connected to a mass that rests on a frictionless surface. A snapshot of this scenario is shown below.

(a) When the mass is at the location shown in the snapshot, what is the direction of the net force on the box?

(1) Left
(2) Right
(3) Zero net force



(b) Which of the following energy diagrams correctly describes this scenario?



$U^S = \frac{1}{2} k x^2$

$F^S_x = -\frac{\Delta U^S}{\Delta x}$

$= -(-)$

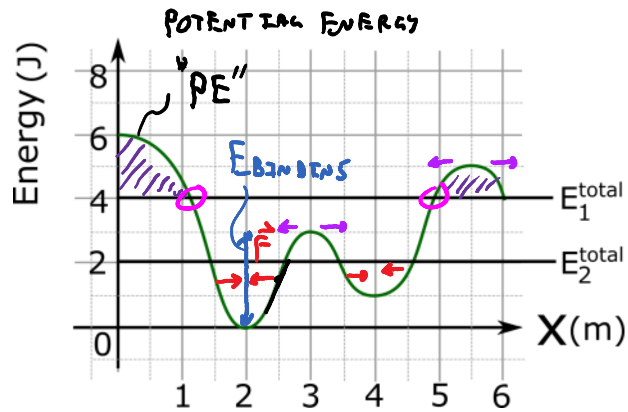
$F^S_x = +$

EA.2.L1-3:

Description: Identify equilibrium locations, forbidden regions, binding energies. (2 minutes + 2 minutes + 2 minutes + 2 minutes + 2 minutes)

Learning Objectives: [1, 2, 3, 4]

Problem Statement: The energy diagram below shows the potential energy as a function of x which has dimensions of length. The two horizontal lines represent two different possibilities of total energy.



(a) What is the direction of the force on the object when it's at location **x** = 2.5 m?

(1) Left
(2) Right
(3) Zero force

$F_x = -\frac{\Delta U}{\Delta x} = -(+)$

$F_x = -$

$\Sigma F_x = 0$

(b) Which of the following locations are equilibrium locations?

SLOPE = 0 @ X = 2m, 3m, 4m, 5.5m

(c) Which of the following locations are stable equilibrium locations?

UNSTABLE? DIVERGENT FORCE

CONVERGENT FORCE

(d) What is the binding energy to overcome the potential barrier between the potential wells at locations 2 and 4?

(1) 0 J
(2) 1 J
(3) 2 J
(4) 3 J
(5) 4 J

(e) With a total energy of **E₁**, what locations would be considered in a forbidden region?

TURNING POINTS! w/ $E^{TOTAL} = E_1$

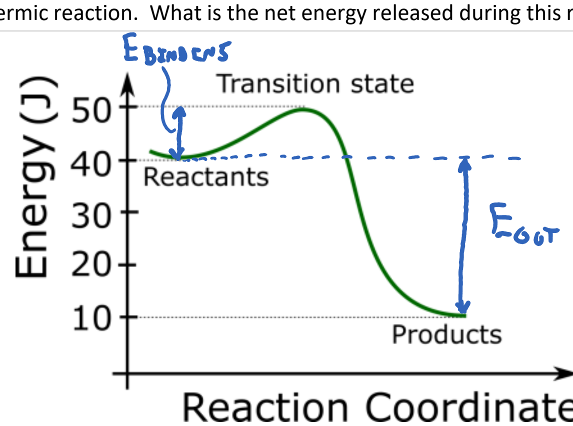
EA.2.L1-4:

Description: Calculate net energy released in reaction. (3 minutes)

Learning Objectives: [4, 5]

Problem Statement: Below is an energy diagram for an exothermic reaction. What is the net energy released during this reaction?

(1) 0 J
(2) 10 J
(3) 30 J
(4) 40



* IF REACTION OCCURS @ CONST. PRESSURE THEN $E_{OUT} = \Delta H$ ~ ENTHALPY

Act II: Macroscopic (earth and solar system) potential energies

EA.2.L1-5:

Description: Determine binding energy given topological map. (3 minutes)

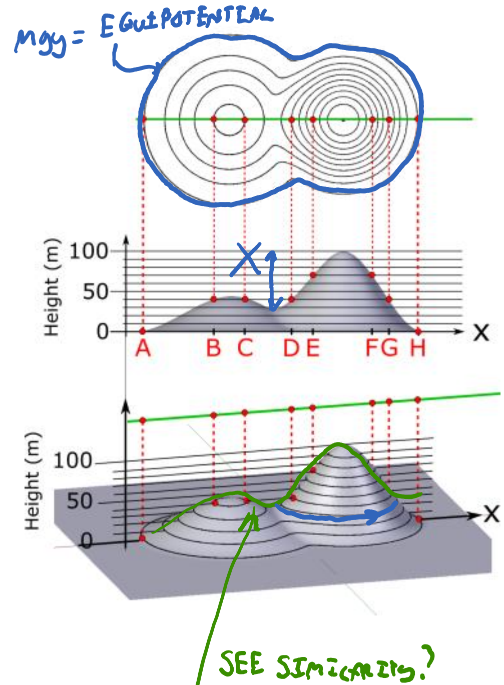
Learning Objectives: [4]

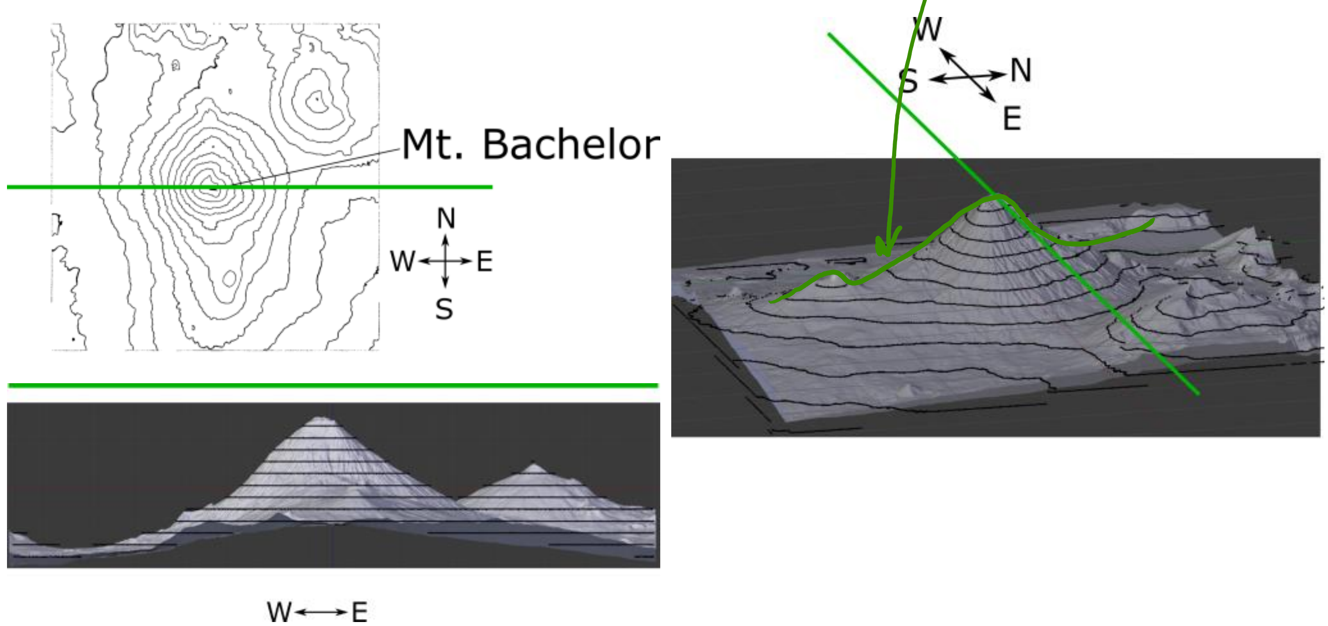
Problem Statement: Starting at the saddle point, what is the binding energy for a 1-kg object to go to location **H**? Assume **g** = 10 m/s^2.

(1) 0 J
(2) 300 J
(3) 700 J
(4) 1000 J

$U^g = mgy$

But it's 2-D so you have options!



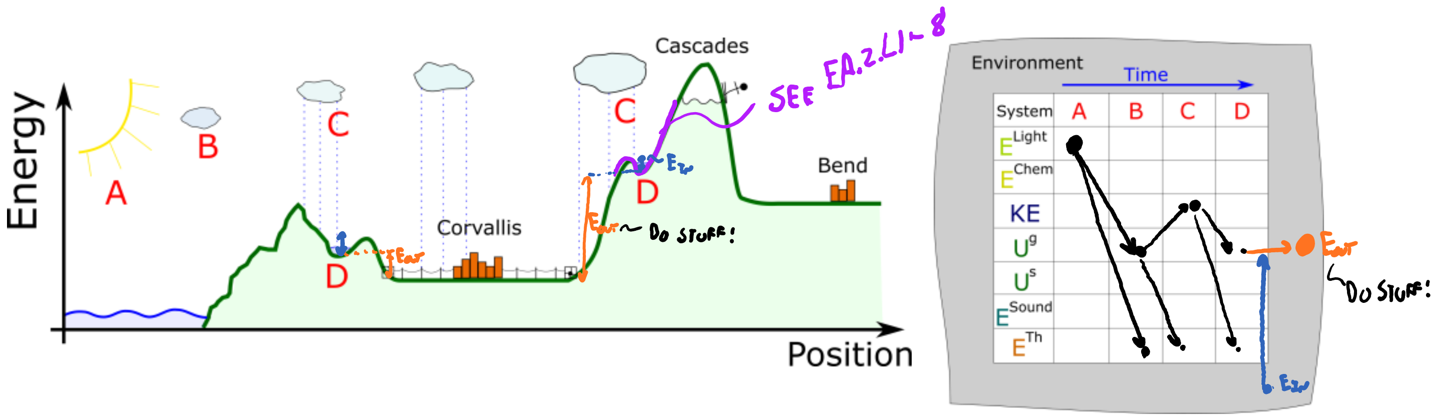


EA.2.L1-6:

Description: Identify energy transformations and transfers. (10 minutes)

Learning Objectives: [7]

Problem Statement: Where does our energy come from?



Act III: Microscopic (molecular and nuclear) potential energies

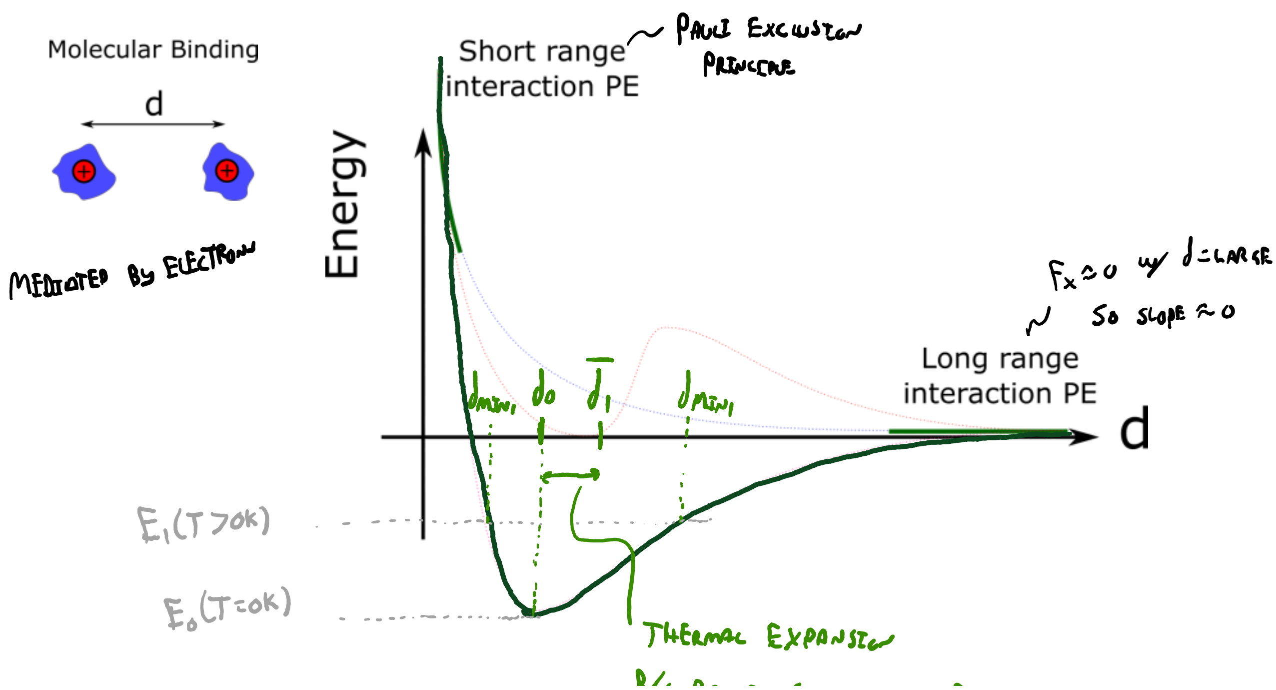
EA.2.L1-7:

Description: Construct molecular binding potential energy plot. (10 minutes)

Learning Objectives: [8]

Problem Statement: Below is a plot of the expected short range and long range interaction energy potential energy (i.e. binding energy) for two molecules. Which dashed line best represents how the short range interaction connects with the long range interaction?

(1) Blue
(2) Red
(3) Pink



$E_0(T=0K)$ ....

THERMAL EXPANSION B/C BROKEN SYMMETRY OF U_{mol}

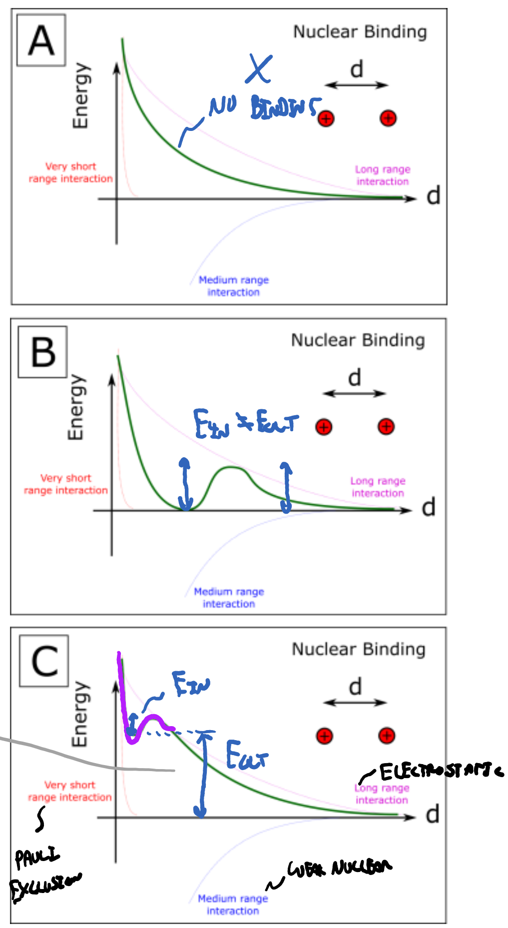
EA.2.L1-8:

Description: Determine nuclear binding potential energy plot. (5)

Learning Objectives: [8]

Problem Statement: Below is a plot of the three contributions to the interaction potential energy (i.e. binding energy) for two protons in a nucleus. Which diagram represents the superposition (net) potential energy?

(1) A
(2) B
(3) C



WAIT... WHAT? TINY BIT OF E_{IN} → LARGE E_{OUT}!

SO... WHAT IS CAPABLE OF PUTTING THAT MUCH ENERGY IN TO GET THE PROTONS TO BIND?..... STARS!!

ALSO ... LOOK AT SHAPE ON EA.2.L1-6... ∴ SAME SHAPE! ... SAME BASIC MODEL!!

Conceptual questions for discussion

1. What are some common features of potential energy plots for objects that are bound together?
2. Using your molecular binding potential energy answer to EA.2.L1-7, explain why molecular bonds are approximated as springs.

Hints

EA.2.L1-1: No hints.

EA.2.L1-2: No hints.

EA.2.L1-3: No hints.

EA.2.L1-4: No hints.

EA.2.L1-5: No hints.

EA.2.L1-6: No hints.

EA.2.L1-7: No hints.

EA.2.L1-8: No hints.