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Appendix

A-1: Lesson Plan for the Ideal Syringe Lab

Class Description: Advanced Placement high-school chemistry or physics, freshman chemistry or physics, and physical chemistry.

Learning Objectives: By the end of this lesson, students should be able to

(1) Develop a particulate model of nature and to use such to be able to explain chemical or physical phenomena such as gas behavior specifically in the contexts of the adiabatic compression/expansion of a gas.

(2) Limitations of and conditions in which models hold and may be applied.

(3) Elastic collisions, conservation of momentum, and kinematics as applied to gas particles.

(4) Greater conceptual understanding of the kinetic molecular theory.

(5) Compare and contrast adiabatic and isothermal compression and expansion.

(6) For introductory students, to do calculations of final pressure and temperature for the adiabatic and isothermal compression/expansion. For college level students, to do calculations of work for both processes.

(7) Use knowledge of adiabatic compression/expansion to explain real-life applications.

Standards: This lesson address the following standards high-school level NSES standards:

CONSERVATION OF ENERGY AND THE INCREASE IN DISORDER. All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves. Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.

MOTIONS AND FORCES. Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F = ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

STRUCTURE AND PROPERTIES OF MATTER. Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart.

Student Preconceptions: It is assumed, depending on the age level of the student, that students should have basic knowledge and familiarity with

(1) Gas laws (Charles law, Gay-Lussac law, Amonton’s law, Boyle’s law, ideal gas law, Graham’s law of effusion).

(2) Definition of pressure and of temperature as related to kinetic energy.

(3) Basic thermodynamics with regards to work done on a system or the system doing work.

Lesson Plan:

I. *Instruction phase*

A. Students are asked to consider and predict the temperature vs. time graph that would be produced when they do the following to a syringe:

(1) Starting from 60 mL, push the plunger of the syringe down to 20 mL as quickly as possible.

(2) Hold the plunger down during the compression at 20 mL for 10 s.

(3) Pull the plunger back to 60 mL after the 10 s hold as quickly as possible without removing the plunger entirely.

(4) Hold the plunger at 60 mL for 10 s.

B. Allow students time to individually come up with predictions. If desired, allow students to form groups and have groups discuss what arguments they used to predict their temperature vs. time graph.

C. Ask students to record their predictions and display their temperature vs. time graphs to the class.

II. *Work Session*

A. Rapid compression/expansion of syringe

(1) Instruct students on how to use the electronic recording device.

(2) If resources are limited, ask students to divide into pairs and simulate the rapid compression/expansion of the syringe. Ask students to repeat the experiment at least once more.

(3) After the rapid compression/expansion, ask students to draw their results (the temperature vs. time graph) for the class to see. Note to students to denote the maximum temperature reached during the compression phase and the minimum temperature reached during the expansion phase.

(4) As individuals, allow students to reconcile their predictions with the observations. Extend this to pairs or groups of students to facilitate discussion.

(5) Have students repeat the experiment this time answering the following prompt "How will the pressure change during the compression/expansion cycle as described above?" Ask students to predict a pressure vs. time graph first and then, using the GLX, switch the scales from temperature to pressure. Have students reconcile their predicted and actual graphs and discuss such with a partner or in a group.

B. Discussion

(1) Ask students to display or verbalize their rationale as to why they predicted the temperature vs. time and pressure vs. time graphs to look the way they predicted. Students are likely to invoke gas laws specifically Boyle's law to inform their answer.

(2) Note to students, during the rapid compression/expansion, the suddenness of the decrease in temperature after compression and the increase in temperature after expansion. In the discussion of the pressure vs. time graph, note a similar trend in the decrease in pressure during the 10 s hold after compression and the increase in pressure during the 10 s hold after expansion.

(3) Help facilitate a discussion amongst students of why they observed the results obtained. That is, ask students to explain how the gas particles heat up (have increased kinetic energy) during the compression, but cool (lose kinetic energy) rapidly after and why the gas particles cool down (have less kinetic energy) during the expansion, but heat up (increase kinetic energy) rapidly after the expansion.

(4) Ask students to give a definition of pressure and ask them how can pressure, in a system, be increased. Two ways are possible, but most students will answer with only one way, that if changing the volume. To guide students, ask them to consider the gas particles as tiny spheres for which Newtonian mechanics could be applied. If this does not help, an analogy such as a ball hitting a moving wall or a collision between cars may facilitate understanding and discussion of elastic collisions. This understanding should allow students to rationalize the pressure vs. time graph observed.

III Assessment phase

A. As a form of assessment, ask students to devise a way to compress/expand the gas such that temperature is nearly constant.

B. Ask students to explain differences and similarities between the rapid (adiabatic) and slow (isothermal) compression/expansion of a gas.

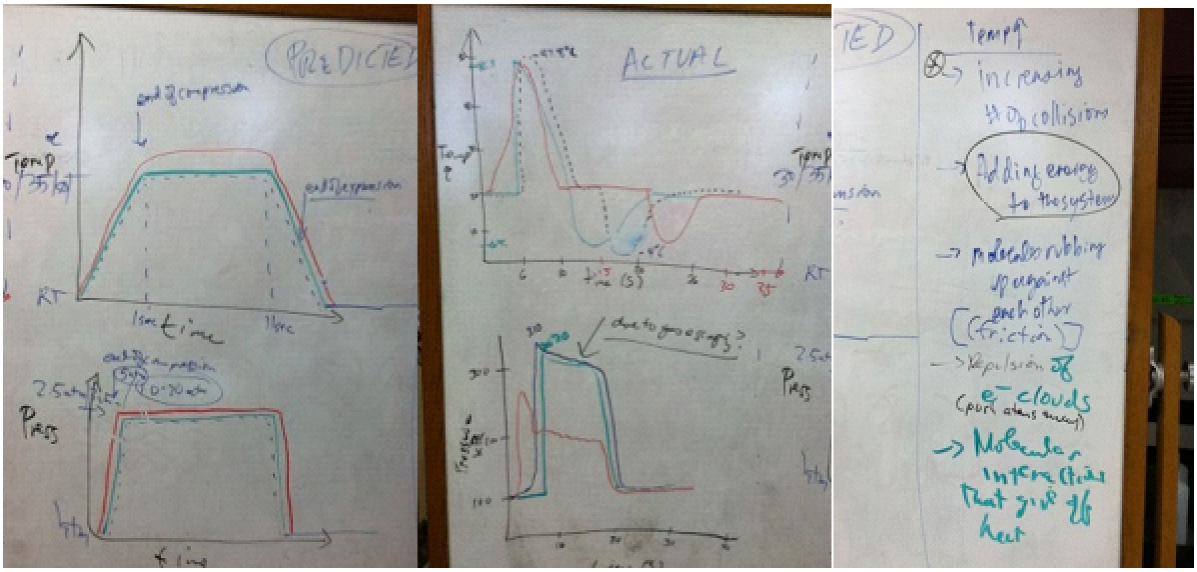
C. Ask students to do some research on compression/expansion of fluids particularly in areas and fields where such is applied in real-life settings. For example, a diesel engine can combust a gas without the use of spark plugs. Students should be able to use their new knowledge to explain why this can occur.

Materials: A PASCO XPlorer GLX as a measuring/recording device was used (see picture below). Along with the recording the device, the other equipment needed can be purchased under the name "Ideal Gas Law Experiment" from PASCO's website (http://www.pasco.com). Vernier offers a similar product that can also be used. (http://www.vernier.com).

Safety and precaution: No extraordinary safety protocols need be followed. Students should be instructed to not disassemble the equipment after use so that they do not remove the thermistor from the syringe.

PASCO XPlorer GLX (PS-2002), PASCO Chemistry Sensor (PS-2170), and PASCO Ideal Gas Law Syringe (TD-8596).

Teachers' Notes: Most students come out, after discussing gas behavior in high school honors chemistry or physics, with the algorithmic conceptualization that a change in pressure will cause a change in temperature. In this lesson, most students, as depicted in **A-2a** will use Boyle's law (PV = const.) argument to predict an increase in pressure and then use Amonton's law (P/T = const.) to predict the temperature increase. Specifically, they will try to correlate the increase in the number of particle-wall collisions (e.g. increased pressure) with increased temperature. Some students may also use the ideal gas law (PV = nRT) to predict the temperature vs. time graph:



A-2: Representative pictures of some student predicted T vs. t and P vs. t graphs for the rapid compression/expansion of the syringe (right), observed student T vs. t and P vs. t graphs (middle), and some student rationales used to argue for their predicted graphs.

They will further assume, without being told, that the syringe is well insulated and that, during the hold, the temperature within the syringe will remain constant. What is hoped in this lesson is that students will develop a more enriched, qualitative model of what is happening at the particulate level with respect to collision theory and the temperature and pressure of a gas. It should be also noted by instructors that the models (algorithms) students invoked to predict their graphs are not without merit, but that they are limited. That is, Boyle's law can only be applied during an isothermal compression/expansion and Amonton's law will work when the volume is fixed.

Definitions:

Pressure. Mathematically, defined as the amount of force, F, exerted per unit area, A, of an object. With respect to gas behavior, it can be considered as the magnitude of the force and number of gas particle-wall collisions in a container at a given volume.

Elastic collision. A collision is said to be elastic if the total kinetic energy between colliding objects is conserved. Students can simulate the gas particles by using sporting goods (tennis ball, soccer ball, basket ball, etc.) and bouncing the ball off the wall. As long as students throw the ball with near constant force, than bouncing the ball off the wall while moving toward the ball should cause the ball to return back to the thrower/kicker more forcefully.

Real-world examples: Heat pumps such as that used in refrigeration or air conditioning and combustion engines (specifically diesel engines) work by the compressing/expanding of a fluid. In the case of a diesel engine, the composition of the fuel is such that the act of compression alone is enough to ignite the fuel without the use of spark plugs (whereas spark plugs are needed in an automobile engine)

A-3: **Syringe Homework Assignment**

1. Using what you know about compression and expansion of gases, can you explain how a diesel engine ignites fuel without a spark plug?

2. Do a little research on compressed air cans (or compressed air dusters).
   a. What happens to the gas when the valve is opened (the can is sprayed)?
   b. Draw a small diagram of the inner contents of the duster during ejection of gas contents and 5-10 minutes after use.

3. Compressing the gas in the ideal gas syringe from 60cc to 20cc is a three-fold compression. The pressure reading from the GLX jumped from ~100kPa to ~315kPa...slightly more than expected. This occurred pretty much every time so device error can be ruled out--what might account for the discrepancy?

4. Draw your graph and the one obtained in this experiment and compare the two. What were your initial thoughts and rationalizations on how the temperature would change? How are your conceptions different now?

5. Identify the difference between an adiabatic and an isothermal compression/expansion.
   a. Explain why slowly compressing the ideal gas syringe resulted in an isothermal graph.
   b. Explain why compressed air cans should not be exposed to open flames or stored at higher temperatures than those recommended on the label.

6. Describe two other commercial processes that use the thermal properties of the compression and expansion of gases in their application.

A-4: Raw data for simulating student predictions to the T vs. t plot for the rapid expansion/compression of an ideal gas in a plastic syringe (**FIG 2 a-c**).

t(s)	T_1 (K)	T_2 (K)	T_3 (K)	t(s)	T_1 (K)	T_2 (K)	T_3 (K)
0	293.15	293.15	293.15	12	293.15	293.15	293.15
1	293.15	293.15	313.15	13	293.15	293.15	293.15
2	293.15	323.15	293.15	14	293.15	293.15	293.15
3	293.15	323.15	293.15	15	293.15	293.15	293.15
4	293.15	323.15	293.15	16	293.15	293.15	293.15
5	293.15	323.15	293.15	17	293.15	293.15	293.15
6	293.15	323.15	293.15	18	293.15	293.15	293.15
7	293.15	323.15	293.15	19	293.15	293.15	293.15
8	293.15	323.15	293.15	20	293.15	293.15	293.15
9	293.15	323.15	293.15	21	293.15	293.15	293.15
10	293.15	323.15	293.15	22	293.15	293.15	293.15
11	293.15	323.15	283.15				

A-5: Raw data for simulating student prediction to the P vs. t plot for the rapid compression of an ideal gas in a plastic syringe (**FIG 4a**).

t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)
0	98	6	294	12	98	18	98
1	98	7	294	13	98	19	98
2	294	8	294	14	98	20	98
3	294	9	294	15	98	21	98
4	294	10	294	16	98	22	98
5	294	11	294	17	98		

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A-6: Sample student data for simulating of the T vs. t plot for the rapid expansion/compression of an ideal gas in a plastic syringe (**FIG 3**).

t(s)[A]	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)
0	298.15	2.6	298.25	5.2	318.75	7.8	303.05	10.4	294.25	13.0	292.05	15.6	296.45	18.2	298.05	20.8	298.45	23.4	298.55
0.1	298.15	2.7	298.25	5.3	316.35	7.9	302.55	10.5	292.05	13.1	292.55	15.7	296.45	18.3	298.05	20.9	298.45	23.5	298.55
0.2	298.15	2.8	298.25	5.4	316.35	8.0	302.55	10.6	292.05	13.2	292.55	15.8	296.65	18.4	298.05	21.0	298.45	23.6	298.55
0.3	298.15	2.9	302.25	5.5	314.15	8.1	302.15	10.7	290.55	13.3	292.55	15.9	296.95	18.5	298.15	21.1	298.45	23.7	298.55
0.4	298.15	3.0	302.25	5.6	314.15	8.2	302.15	10.8	290.55	13.4	292.95	16.0	296.95	18.6	298.15	21.2	298.45	23.8	298.55
0.5	298.15	3.1	311.65	5.7	312.15	8.3	301.85	10.9	289.65	13.5	292.95	16.1	296.95	18.7	298.15	21.3	298.45	23.9	298.55
0.6	298.15	3.2	311.65	5.8	312.15	8.4	301.85	11.0	289.65	13.6	293.35	16.2	296.95	18.8	298.15	21.4	298.45	24.0	298.55
0.7	298.15	3.3	321.65	5.9	310.45	8.5	301.55	11.1	289.65	13.7	293.35	16.3	297.05	18.9	298.25	21.5	298.45	24.1	298.55
0.8	298.15	3.4	321.65	6.0	310.45	8.6	301.55	11.2	289.35	13.8	293.75	16.4	297.05	19.0	298.25	21.6	298.45	24.2	298.55
0.9	298.15	3.5	328.85	6.1	308.95	8.7	301.55	11.3	289.35	13.9	293.75	16.5	297.25	19.1	298.25	21.7	298.45	24.3	298.55
1.0	298.15	3.6	328.85	6.2	308.95	8.8	301.25	11.4	289.35	14.0	294.15	16.6	297.25	19.2	298.25	21.8	298.55	24.4	298.55
1.1	298.15	3.7	331.65	6.3	308.95	8.9	301.25	11.5	289.35	14.1	294.15	16.7	297.45	19.3	298.25	21.9	298.55	24.5	298.55
1.2	298.15	3.8	331.65	6.4	307.55	9.0	300.95	11.6	289.55	14.2	294.15	16.8	297.45	19.4	298.35	22.0	298.55	24.6	298.55
1.3	298.15	3.9	331.65	6.5	307.55	9.1	300.95	11.7	289.35	14.3	294.55	16.9	297.55	19.5	298.35	22.1	298.55	24.7	298.55
1.4	298.15	4.0	330.85	6.6	306.35	9.2	300.75	11.8	289.95	14.4	294.55	17.0	297.55	19.6	298.35	22.2	298.55	24.8	298.55
1.5	298.15	4.1	330.85	6.7	306.35	9.3	300.75	11.9	289.35	14.5	294.85	17.1	297.65	19.7	298.35	22.3	298.55	24.9	298.55
1.6	298.15	4.2	328.85	6.8	305.45	9.4	300.55	12.0	290.25	14.6	294.85	17.2	297.75	19.8	298.35	22.4	298.55	25.0	298.55
1.7	298.15	4.3	328.85	6.9	305.45	9.5	300.55	12.1	290.25	14.7	295.25	17.3	297.65	19.9	298.35	22.5	298.55	25.1	298.55
1.8	298.15	4.4	326.55	7.0	304.65	9.6	300.35	12.2	290.25	14.8	295.25	17.4	297.75	20.0	298.35	22.6	298.55	25.2	298.55
1.9	298.15	4.5	326.55	7.1	304.65	9.7	300.35	12.3	290.75	14.9	295.55	17.5	297.75	20.1	298.35	22.7	298.55	25.3	298.55
2.0	298.15	4.6	324.05	7.2	304.05	9.8	299.75	12.4	290.75	15.0	295.55	17.6	297.85	20.2	298.45	22.8	298.55	25.4	298.55
2.1	298.15	4.7	324.05	7.3	304.05	9.9	299.75	12.5	291.25	15.1	295.85	17.7	297.85	20.3	298.45	22.9	298.55	25.5	298.55
2.2	298.15	4.8	321.35	7.4	303.55	10.0	299.75	12.6	291.25	15.2	295.85	17.8	297.95	20.4	298.45	23.0	298.55	25.6	298.55
2.3	298.15	4.9	321.35	7.5	303.55	10.1	296.95	12.7	291.65	15.3	295.85	17.9	297.95	20.5	298.45	23.1	298.55	25.7	298.55
2.4	298.15	5.0	318.75	7.6	303.55	10.2	296.95	12.8	291.65	15.4	296.15	18.0	298.05	20.6	298.45	23.2	298.55	25.8	298.55
2.5	298.15	5.1	318.75	7.7	303.05	10.3	294.25	12.9	292.05	15.5	296.15	18.1	298.05	20.7	298.45	23.3	298.55		

[A]Original raw data contained 2582 data points of which 250 are given here by taking 0.1 s time increments instead of the original 0.01 s time increments.

A-7: Sample student data for simulating the P vs. t plot for the rapid expansion/compression of an ideal gas in a plastic syringe (**FIG 4b**).

t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)	t(s)	P(kPa)
0	97	2.0	97	4.0	317	6.0	279	8.0	263	10.0	260	12.0	249	14.0	95	16.0	97
0.1	97	2.1	97	4.1	311	6.1	279	8.1	263	10.1	260	12.1	249	14.1	95	16.1	97
0.2	97	2.2	97	4.2	307	6.2	278	8.2	263	10.2	259	12.2	249	14.2	94	16.2	97
0.3	97	2.3	97	4.3	303	6.3	277	8.3	264	10.3	258	12.3	249	14.3	94	16.3	97
0.4	97	2.4	97	4.4	299	6.4	276	8.4	264	10.4	256	12.4	249	14.4	94	16.4	97
0.5	97	2.5	97	4.5	296	6.5	275	8.5	264	10.5	255	12.5	248	14.5	94	16.5	97
0.6	97	2.6	97	4.6	294	6.6	274	8.6	264	10.6	255	12.6	248	14.6	94	16.6	97
0.7	97	2.7	97	4.7	292	6.7	273	8.7	264	10.7	254	12.7	247	14.7	95	16.7	97
0.8	97	2.8	97	4.8	290	6.8	272	8.8	264	10.8	253	12.8	244	14.8	95	16.8	97
0.9	97	2.9	97	4.9	289	6.9	270	8.9	263	10.9	253	12.9	230	14.9	95	16.9	97
1.0	97	3.0	97	5.0	288	7.0	269	9.0	262	11.0	252	13.0	193	15.0	95	17.0	97
1.1	97	3.1	97	5.1	287	7.1	268	9.1	262	11.1	250	13.1	153	15.1	96	17.1	97
1.2	97	3.2	97	5.2	285	7.2	267	9.2	262	11.2	249	13.2	127	15.2	96	17.2	97
1.3	97	3.3	136	5.3	285	7.3	266	9.3	262	11.3	249	13.3	110	15.3	96	17.3	97
1.4	97	3.4	253	5.4	284	7.4	266	9.4	262	11.4	249	13.4	102	15.4	96	17.4	97
1.5	97	3.5	304	5.5	283	7.5	264	9.5	262	11.5	249	13.5	96	15.5	97	17.5	97
1.6	97	3.6	322	5.6	282	7.6	263	9.6	261	11.6	249	13.6	94	15.6	97	17.6	97
1.7	97	3.7	324	5.7	281	7.7	263	9.7	261	11.7	248	13.7	95	15.7	97		
1.8	97	3.8	327	5.8	280	7.8	263	9.8	261	11.8	248	13.8	95	15.8	97		
1.9	97	3.9	324	5.9	280	7.9	263	9.9	260	11.9	249	13.9	95	15.9	97		

A-8: Sample student data for simulating the T vs. t plot for the slow compression of an ideal gas in a plastic syringe (**FIG 5**).

t(s)[A]	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)	t(s)	T(K)
0	298.65	21	298.95	42	298.85	63	298.85	84	298.75	105	298.65	126	298.65	147	298.65	168	298.65	189	298.05	210	298.85
1	298.65	22	298.95	43	298.95	64	298.85	85	298.75	106	298.75	127	298.65	148	298.75	169	298.75	190	298.75	211	298.75
2	298.65	23	298.95	44	298.85	65	298.85	86	298.75	107	298.75	128	298.65	149	298.75	170	298.75	191	298.75	212	298.65
3	298.75	24	298.95	45	298.85	66	298.85	87	298.75	108	298.75	129	298.75	150	298.65	171	298.65	192	298.85	213	298.65
4	298.75	25	298.95	46	298.85	67	298.85	88	298.75	109	298.75	130	298.75	151	298.65	172	298.65	193	298.75	214	298.75
5	298.75	26	298.85	47	298.85	68	298.75	89	298.75	110	298.65	131	298.65	152	298.75	173	298.65	194	298.65	215	298.75
6	298.75	27	298.85	48	298.85	69	298.75	90	298.75	111	298.75	132	298.65	153	298.65	174	298.65	195	298.65	216	298.75
7	298.95	28	298.85	49	298.75	70	298.75	91	298.85	112	298.75	133	298.65	154	298.65	175	298.65	196	298.75	217	298.95
8	298.95	29	298.85	50	298.75	71	298.75	92	298.85	113	298.85	134	298.65	155	298.65	176	298.65	197	298.75	218	298.75
9	298.85	30	298.95	51	298.85	72	298.85	93	298.85	114	298.75	135	298.65	156	298.65	177	298.75	198	298.65	219	298.75
10	298.85	31	298.95	52	298.85	73	298.85	94	298.85	115	298.75	136	298.65	157	298.65	178	298.75	199	298.65		
11	298.85	32	298.95	53	298.85	74	298.85	95	298.75	116	298.85	137	298.65	158	298.65	179	298.75	200	298.65		
12	298.85	33	298.95	54	298.85	75	298.85	96	298.75	117	298.85	138	298.65	159	298.65	180	298.85	201	298.55		
13	298.85	34	298.95	55	298.85	76	298.85	97	298.75	118	298.75	139	298.75	160	298.65	181	298.85	202	298.55		
14	298.85	35	298.95	56	298.85	77	298.85	98	298.75	119	298.75	140	298.75	161	298.65	182	298.75	203	298.75		
15	298.85	36	298.95	57	298.85	78	298.85	99	298.75	120	298.75	141	298.75	162	298.65	183	298.75	204	298.75		
16	298.95	37	298.95	58	298.85	79	298.85	100	298.85	121	298.75	142	298.65	163	298.65	184	298.85	205	298.75		
17	298.95	38	298.85	59	298.85	80	298.85	101	298.85	122	298.75	143	298.65	164	298.55	185	298.75	206	298.65		
18	298.95	39	298.85	60	298.85	81	298.85	102	298.75	123	298.65	144	298.65	165	298.65	186	298.55	207	298.75		
19	298.95	40	298.85	61	298.85	82	298.85	103	298.75	124	298.65	145	298.65	166	298.75	187	298.35	208	298.75		
20	298.95	41	298.85	62	298.85	83	298.85	104	298.75	125	298.65	146	298.65	167	298.75	188	298.55	209	298.75		

[A]Original raw data contained 21979 data points using 0.01 s time increments; this was reduced to 219 data points using 1 s time increments.

A-9: Sample student data for the PV plot for the slow compression of an ideal gas in a plastic syringe (**FIG 6**).

P(kPa)[A]	**V**[A] **(10^{-5} m^3)**	**P(kPa)**	**V (10^{-5} m^3)**	**P(kPa)**	**V (10^{-5} m^3)**	**P(kPa)**	**V (10^{-5} m^3)**	**P(kPa)**	**V (10^{-5} m^3)**	**P(kPa)**	**V (10^{-5} m^3)**	**P(kPa)**	**V (10^{-5} m^3)**
98	6.08	105	5.68	112	5.32	125	4.77	139	4.29	159	3.75	182	3.28
98	6.08	105	5.68	112	5.32	125	4.77	140	4.26	160	3.73	182	3.28
98	6.08	105	5.68	113	5.28	126	4.73	141	4.23	161	3.70	183	3.26
98	6.08	106	5.62	113	5.28	127	4.69	141	4.23	162	3.68	185	3.22
98	6.08	106	5.62	114	5.23	127	4.69	142	4.20	163	3.66	186	3.21
98	6.08	106	5.62	114	5.23	127	4.69	142	4.20	164	3.64	187	3.19
99	6.02	106	5.62	114	5.23	127	4.69	143	4.17	165	3.61	187	3.19
99	6.02	107	5.57	115	5.18	128	4.66	143	4.17	167	3.57	187	3.19
99	6.02	106	5.62	116	5.14	129	4.62	143	4.17	167	3.57	188	3.17
99	6.02	107	5.57	116	5.14	130	4.59	144	4.14	167	3.57	189	3.15
99	6.02	107	5.57	116	5.14	130	4.59	144	4.14	168	3.55	190	3.14
99	6.02	107	5.57	117	5.10	130	4.59	146	4.08	169	3.53	191	3.12
99	6.02	107	5.57	117	5.10	131	4.55	145	4.11	169	3.53	193	3.09
99	6.02	107	5.57	117	5.10	132	4.52	146	4.08	168	3.55	193	3.09
99	6.02	107	5.57	118	5.05	132	4.52	147	4.06	168	3.55	193	3.09
100	5.96	107	5.57	118	5.05	132	4.52	148	4.03	169	3.53		
100	5.96	108	5.52	118	5.05	133	4.48	148	4.03	171	3.49		
101	5.90	108	5.52	119	5.01	133	4.48	148	4.03	172	3.47		
101	5.90	108	5.52	119	5.01	133	4.48	149	4.00	173	3.45		
102	5.85	109	5.47	120	4.97	134	4.45	149	4.00	174	3.43		
102	5.85	109	5.47	120	4.97	134	4.45	150	3.97	174	3.43		
102	5.85	109	5.47	121	4.93	135	4.42	151	3.95	174	3.43		
103	5.79	109	5.47	122	4.89	135	4.42	151	3.95	176	3.39		
103	5.79	110	5.42	122	4.89	135	4.42	151	3.95	176	3.39		
103	5.79	110	5.42	122	4.89	135	4.42	152	3.92	176	3.39		
103	5.79	111	5.37	122	4.89	137	4.35	152	3.92	177	3.37		
103	5.79	111	5.37	123	4.85	137	4.35	153	3.90	177	3.37		
103	5.79	111	5.37	123	4.85	137	4.35	154	3.87	178	3.35		
104	5.73	111	5.37	123	4.85	137	4.35	156	3.82	178	3.35		
104	5.73	112	5.32	124	4.81	138	4.32	156	3.82	178	3.35		
104	5.73	112	5.32	124	4.81	138	4.32	158	3.77	179	3.33		
104	5.73	112	5.32	125	4.77	139	4.29	158	3.77	181	3.29		
105	5.68	112	5.32	125	4.77	139	4.29	158	3.77	181	3.29		

[A]Original raw data contained 21979 data points using 0.01 s time increments; this was reduced to 219 data points using 1 s time increments. Both P and V values in the above is derived from these time increment values.

A-10: Sample student data for the PV plot for the rapid compression of an ideal gas in a plastic syringe (**FIG 6**).

P(kPa)[A]	V[A] (10^{-5} m^3)	P(kPa)	V (10^{-5} m^3)	P(kPa)	V (10^{-5} m^3)	P(kPa)	V (10^{-5} m^3)	P(kPa)	V (10^{-5} m^3)
99	6.01	145	4.58	230	3.29	274	2.90	306	2.68
100	5.97	149	4.49	232	3.27	275	2.90	308	2.67
100	5.97	154	4.38	235	3.24	276	2.89	311	2.65
101	5.92	161	4.25	237	3.22	277	2.88	313	2.64
102	5.88	167	4.14	240	3.19	278	2.87	316	2.62
103	5.84	172	4.05	243	3.16	279	2.87	318	2.61
105	5.76	176	3.98	248	3.12	281	2.85	319	2.61
107	5.69	181	3.91	252	3.08	282	2.85	319	2.61
110	5.57	186	3.83	256	3.05	283	2.84	319	2.61
113	5.47	191	3.76	259	3.02	285	2.82	319	2.61
117	5.33	196	3.69	261	3.01	286	2.82	319	2.61
120	5.24	199	3.65	263	2.99	289	2.80		
123	5.15	203	3.60	264	2.98	291	2.78		
126	5.06	206	3.56	265	2.97	293	2.77		
129	4.97	212	3.49	267	2.96	296	2.75		
132	4.89	216	3.44	269	2.94	298	2.74		
136	4.79	221	3.39	271	2.93	302	2.71		
141	4.67	226	3.33	272	2.92	304	2.70		

[A]The data in the above is taken from the P values determined from time 2.54 to 3.36 with 0.01 s time increments (83 points). V values were calculated.