Lesson Title:	**Thermal Dynamics**
Subject Area:	Science/Physics
Grade Level:	8-12
Duration:	10-12 days
Format (#Students/group):	20-24 students working individually initially, but then completing all measurements for comparison in pairs. Introduction: reading a ruler (tape measure) using calipers, micrometers, activity, converting fractional to decimal and vise versa. Introduction to spreadsheets, recording/entering data. Introduction to the materials (wood, plastic, metal, composite).
Overview:	Students will learn how to read various measurement tools (tape measure, micrometer and inch calipers) and then determine how temperature affects the measurements of different materials. Students will also learn about tolerances and what issues arise due to temperature differences.
Educational Standards:	NGSS MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added. HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* ACT Quality Core Scientific Inquiry a. Identify and clarify research questions and design experiments b. Collect, organize, and analyze data accurately and use appropriate techniques and devices d. Interpret results and draw conclusions, revising hypotheses as necessary and/or formulating additional questions or explanations

Lesson Title:	**Thermal Dynamics**
	f. Safely use laboratory equipment and techniques when conducting scientific investigations Mathematics and measurement in science a. Distinguish between precision and accuracy with respect to experimental data b. Use appropriate SI units for length, mass, time, temperature, area, volume, and density; describe the relationships among SI unit prefixes (e.g., centi-, milli-, kilo-) and how to convert between English units and SI units.
Unit Question:	How does changes in temperature affect measurement? (Tolerances)
Focus Question/ Purpose:	Measuring and the use of math are used every day in manufacturing. Thus employees must have the skills necessary to accurately measure and determine if production pieces are within acceptable ranges for the customers purchasing their products. Therefore, can students accurately and precisely utilize the tools used in manufacturing to measure parts within 1/1000th of an inch.
Desired Outcomes:	Students will learn how to read and understand a multitude of measuring devices and also understand how temperature changes can affect the expansion or contraction of the materials. Students will also attempt to understand how such temperature changes can affect “tight” tolerances often used in manufacturing.
Activity Details/ Instructions:	1. Introduction (how to read a tape measure, caliper and micrometers) 2. Introduction to spreadsheets, entering data. 3. Introduction to various materials and recording measurements of them (at least measurements of one of each type of object (Ruler, Caliper, Micrometer, thickness gauge). Base line measurement at room temperature. 4. Materials then placed in two environments (Freezer 0º) and others heated with Bunsen burner. 5. Items placed in the freezer were put in zip lock bags and when students were to measure them, they were not to touch the material with their bare hands thus limiting the transfer of heat from them to the object they were measuring.
Safety:	Hot mitts or oven gloves will be required for items that are heated. Be careful not to heat items to that may catch fire or melt. Calipers used for measuring i.d. and o.d. must be metal not plastic. Safety glasses and hot mitts MUST be worn when heating an object.
Potential Cost:	Density cube set: ~$40. Density Cylinder Set: ~$50. 6” Manual Calipers $2.99 each (Harbor Freight). Micrometer set of 3. $40 (Harbor Freight). 1- 6” digital calipers $20 (Harbor Freight). Digital Thickness gauge $6.99 each (Harbor Freight). NOTE: Harbor Freight only sells the plastic calipers for fractional reading, thus they cannot be used for measuring items that are heated. Northern Tool sells a jumbo caliper (Grip Jumbo Aluminum Caliper — 24in. Jaw, Model# 59070). The numbers are much larger on this caliper and easier for students to read.
Supplies (sources):	Micrometers (digital and manual) Cooling source, heat source, different types of wood (oak, pine, balsa), metal (aluminum, steel, cast iron, copper, stainless steel, brass, etc. Even different types of bolts). Different types of plastics. Density material kit(s) round cylinders as well as cube set.

Lesson Title:	**Thermal Dynamics**
Developed by:	Stewart Kieliszewski
Date:	Fall 2015
Key Words:	STEM,
Other Resources:	How to read a vernier caliper easy [https://youtu.be/StBc56ZifMs] How to read an inch micrometer [https://youtu.be/p9M90hMAM2o] Reading a Standard Micrometer [https://youtu.be/i_jygJkJujE] Read a vernier caliper in INCHES, measure a ball bearing [https://youtu.be/S_zsEPIN1EI] Read a vernier caliper in METRIC, measure saw set [https://youtu.be/5VG8-nlhA8k] How to Read a Metric Micrometer [https://youtu.be/StBc56ZifMs]

Other ideas: have different students measure the same object with a ruler. Have them enter the data into a spreadsheet (tolerances are set to allow some to pass and some not). Then as some objects pass and some objects do not, then ask why are some passing and others not? We are all measuring the same exact thing/item.

Then get out the real measuring tools and then redo the experiment, how many are now within the tolerance?

Also you could say, as long the material meets specs, what would be the best material to use? What would be the cheapest? Etc.

Day 1 Introduction: (1-2 days)

Have students utilize their I-pads if available to open a new excel worksheet. Inform students that they are going to perform several measurements and that they will have to keep accurate records of their measurements. You may have to take the time to show them how to enter data within the cells of the spreadsheet. You may want to have them enter the name or the letter of the object they will measure and if they are measuring length, width and height, thickness or inside diameter and outside diameter.

	A	B	C	D	E	F
1	Object	Length	Width	Height/Thickness	Inside Diameter	Outside Diameter
2	A (2" x 4")				X	X
3	B (PVC Connector)		X	X		

Introduce students to the tape measure they will be using. I had students work in pairs initially and we all measured the same item to determine its measurements. This is where I was able to help with some confusion in reading the tape measure and students could help each other as well.

Here are a couple of YouTube videos you can have students watch to help them: How to Read an Inch Ruler or Tape Measure [https://youtu.be/RQOBkOJQFwE] for inch only and Read an inch ruler in 32nds [https://youtu.be/rf9fvXcaSIk] for reading 1/32 inch rulers/tape measures.

Introduce the students to the materials they are to measure and the type of measurements they will be taking (length, width, height/thickness, inside diameter and outside diameter). You may want to display your spreadsheet of items they are to measure or you can simply label each item with what type of measurement they are to take.

Have several different types of materials out that are labeled A-?? for students to begin measuring with a tape measure. NOTE: Attempt to find and utilize tape measures that can measure to 1/32 and or 1/64th.

Materials: Chunk of 2" x 4" (measuring length, width, and height/thickness). Chunk of plywood, flat steel, aluminum, rubber, plastic, etc.

Allow students to move from station to station completing the measurements.

Day 2 or 3 Measurement Comparison: (1 day)

Have the students open their spreadsheet of measurements and ask student volunteers to read off their measurements. You could have the student's type in question marks (??) next to the measurements that are really off. Once the measurement readings are done, then ask for student volunteers to question measurement errors. You can ask students who got the answers right or really close to demonstrate how they got the measurements they did. REMINDER: Be sure to have the students place in the inch (") marks for each of their readings.

A	B	C	D	E	F
Object	Length	Width	Height/Thickness	Inside Diameter	Outside Diameter
A (2" x 4")	1 1/32"	3 1/2"	1 1/2"	X	X
B (PVC Connector)	7/8"	X	X	19/32"	27/32"

Give time for students to go back and double-check their measurements and to ensure they are reading the tape measure and listing their fractions correctly. You can then have the students convert their fractions into decimals and place the decimal readings in parenthesis next to their fractional readings.

A	B	C	D	E	F
Object	Length	Width	Height/Thickness	Inside Diameter	Outside Diameter
A (2" x 4")	1 1/32" (1.03125")	3 1/2 (3.5)	1 1/2" (1.5")	X	X
B (PVC Connector)	7/8" (.875)	X	X	19/32" (.59375")	27/32" (.84375")

You can then announce a quiz for the students that will take place on the next day.

Day 4 Measurement quiz: (1 day)

Students will take their quiz moving to various stations entering their measurements into a printed spreadsheet. If time permits, you can correct the quiz or allow the students to begin looking at the micrometer sets and calipers and view the videos that show them how to read these instruments.

Day 5 Micrometer and Caliper introduction: (1 day)

Introduce students to the micrometers they will be using: 0-1", 1-2" and 2-3". Once again, I had students work in pairs initially and we all measured the same items: 1-0-1" item (a washer) 1-1-2" item (bolt length) and a 2-3" item (a chunk of dowel rod) to determine their measurements. This is where I was able to help with some confusion in reading the micrometers and students could help each other as well.

I had the students (as a group) watch the YouTube video on reading an inch micrometer How to read an inch micrometer [https://youtu.be/p9M90hMAM2o]

I also had the students (as a group) watch the YouTube video on reading an inch caliper [How to read an inch caliper](https://youtu.be/S_zsEPIN1EI)[https://youtu.be/S_zsEPIN1EI]

As the students watched the video, I paused it at points for them to get the readings.

Allow students time to measure each and every item, once again keeping track of the measurements within a new excel worksheet (items should be either listed on your sample spreadsheet or at each station).

Day 6 Micrometer and Caliper Reading: (1-2 days)

Introduce the students to the materials they are to measure and the type of measurements they will be taking (length, thickness, inside diameter and outside diameter). You may want to display your spreadsheet of items they are to measure or you can simply label each item with what type of measurement they are to take.

Have several different types of materials out that are labeled A-??

> Materials: Washers and bolts of various thickness, copper pipe & or connectors, brass pipe, stainless steel pipe, density cubes and cylinders, etc.

HINT: I found it easier to set up the stations with the items and placed the instrument they were to measure with at that station along with the type(s) of measurement they were to take. I did this on large pieces of construction paper.

Allow students to move from station to station completing the measurements.

(See folder for "Measurement Practice" I used for this activity)

Day 8 Measurement comparison: (1 day)

Have the students open their spreadsheet of measurements and ask student volunteers to read off their measurements. You could have the student's type in question marks (??) next to the measurements that are really off. Once the measurement readings are done, then ask for student volunteers to question measurement errors. You can ask students who got the answers right or really close to demonstrate how they got the measurements they did. REMINDER: Be sure to have the students place in the inch (") marks for each of their readings.

Announce Micrometer and Caliper reading quiz for the next day.

Day 9 Micrometer and Caliper Reading quiz: (1 day)

Students will take a quiz at various stations entering their measurements into a printed spreadsheet.

(See folder for the "measurement quiz blank" I used)

Note: I only allowed individual students to remain at each station for 1 minute and 30 seconds to get their measurements.

Day 10 Micrometer and Caliper Reading quiz correction and Thermal team setup: (1 day)

Randomly handout the quizzes to be checked, noting the tolerances (range) for each item. If they were within range, students received all 3 points fore each measurement, slightly out of range 2 out of 3 and so on.

Day 11 Micrometer and Caliper Reading with heating and cooling: (1 day) Homework + Handout

Set up heating teams and cooling team measurements. I found within my class that there were a few students that I could trust working with Bunsen burners safely and others I was not sure about. The students I was unsure about did the safe measurements.

(See folder for "Δ Exp-Cont Data Sheet Blank" I used for this activity)

Day 12 Micrometer and Caliper heating and cooling correction of homework and handout: (1 day)

(See folder for the "measurement teams blank", "measurements key" and "living thermal expansion and contraction key" I used for this activity)

Heating Teams

Students 1 & 2	#9 (Brass Sleeve)****
Students 3 & 4	#4 (Copper Connector)****
Students 5 & 6	#1 (Small Bearing)
Students 7 & 8	#15 (Stainless pipe)****
Students 9 & 10	#12 (Small Steel Dowel)
Students 11 & 12	#6 (Steel Sleeve)

**** USE METAL CALIPER

Freeze measurements

Student 13	#14 (Large PVC)
Student 14	#7 (Long Steel Dowel)
Student 15	#8 (Grinder Wheel)
Student 16	#11 (Rubber Spacer)
Student 17	#10 (Grey PVC)
Student 18	#5 (Plastic Spacer)
Student 20	#13 (Aluminum Dowel)
Student 21	#2 (Large Bearing)

NOTE: You can pair up students in 13-21 if you need extra spaces to put them. Students working in pairs also help to ensure the accuracy of the measurement reading.

Item/instrument	#	I.D.	O.D.	Thickness	Length	Width
Large PVC 1-2" for O.D. Caliper for I.D.				=============	=============	=============
Small PVC Caliper for both I.D. & O.D.				=============	=============	=============
Copper T Caliper for both I.D. & O.D.				=============	=============	=============
Large Copper Pipe Caliper for both I.D. & O.D.				=============	=============	=============
Small Copper Pipe Caliper for both I.D. & O.D.				=============	=============	=============
Hex Nut 1-2" Micrometer		=============	=============	=============	=============	
Aluminum Nail 0-1" No #	No #	=============		=============	=============	=============
6 Penney Nail 0-1" No #	No #	=============		=============	=============	=============
8 Penney Nail 0-1" No #	No #	=============		=============	=============	=============
Measuring Stick 0-1" thickness 1-2" width		=============	=============		=============	
Small pins 0-1 O.D. & Length	No #	=============		=============		=============
Object D Caliper O.D. & 2-3" Length	**D**	=============		=============		=============
Object E Caliper O.D. & 2-3" Length	**E**	=============		=============		=============
Object F Caliper O.D. & 2-3" Length	**F**	=============		=============		=============
Object K Caliper O.D. & 2-3" Length	**K**	=============		=============		=============
Aluminum Ear 0-1" Thickness 1-2" Width		=============	=============		=============	

Name ______________________________

Station	Item	Instrument	RT O.D.	Δ O.D.	% Exp/Cont	RT I.D.	Δ I.D.	% Exp/Cont	RT Length	Δ Length	% Exp/Cont	RT Thickness	Δ Thickness	% Exp/Cont	Measurements
1	Bearing H	0-1" mic				X	X	X	X	X	X	Center			2
2	Bearing C	1-2" mic				X	X	X	X	X	X	X	X	X	1
4	Copper Connector H	Caliper	X	X	X							X	X	X	2
5	Plastic Spacer C	0-1" Mic				X	X	X				X	X	X	2
6	Steel Sleeve H	1-2" mic	X	X	X	X	X	X				X	X	X	1
7	Steel Dowel C	2-3" Mic	X	X	X	X	X	X				X	X	X	1
8	Grinder Wheel C	Caliper							X	X	X	X	X	X	2
9	Brass Sleeve H	Caliper							X	X	X	X	X	X	2
10	Gray PVE C	Caliper				X	X	X				X	X	X	2
11	Rubber Spacer C	0-1" mic				X	X	X	X	X	X				2
12	Steel Dowel H	1-2" mic	X	X	X	X	X	X				X	X	X	1
13	Aluminum Dowel C	2-3 mic				X	X	X	X	X	X	X	X	X	1
14	Large PVC C	Caliper				X	X	X				X	X	X	2
15	Stainless Pipe H	Caliper							X	X	X	X	X	X	1
															22

Which material or item had the greatest amount of expansion? ____

What was the % of expansion? ________________

Which material or item had the greatest amount of contraction? ____

What was the % of contraction? ________________

Micrometer/Caliper Test

Name ___________________________

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Be sure to complete the measurements with the instruments provided. Some measurements will be in decimal form (micrometer) and others will be in fractional form (caliper).

Station	Item	Instrument	O.D.	I.D.	Length	Thickness	Measurements	Range
1	Bearing	0-1" mic		X	X	Center	2	
2	Bearing	1-2" mic		X	X	Center	1	
3	Wood Dowel L	2-3 mic & Caliper		X		X	2	
4	Copper Connector	Caliper				X	3	
5	Plastic Spacer	0-1" Mic		X		X	2	
6	Steel Sleeve	1-2" mic	X	X		X	1	
7	Steel Dowel	2-3 mic & Caliper		X		X	2	
8	Grinder Wheel	Caliper			X		3	
9	Brass Sleeve	Caliper			X	X	2	
10	Gray PVE	Caliper				X	3	
11	Rubber Spacer	0-1" mic		X	X		2	
12	Steel Dowel	1-2" mic	x	X		X	1	
13	Aluminum Dowel	2-3 mic & Caliper		X		X	2	
14	Large PVC	Caliper				X	3	
15	Stainless Pipe	Caliper			X	X	2	
							31	

Station	Item	Instrument	O.D.	Range	I.D.	Range	Length	Range	Thickness	Range	Measurements
1	Bearing	0-1" mic	0.875	.872-.878	X	X	X	X	Center .280	.278-.282	2
2	Bearing	1-2" mic	1.126	1.123-1.129	X	X	X	X	X	X	1
3	Wood Dowel L	2-3 mic & Caliper	7/8	55/64-115/128	X	X	2.463	2.460-2.466	X	X	2
4	Copper Connector	Caliper	1 31/64	61/128-63/128	1 3/8	23/128 25/128	2 3/64	1/64-7/128	X	X	3
5	Plastic Spacer	0-1" Mic	0.741	.735-.747	X	X	0.851	.845-.857	X	X	2
6	Steel Sleeve	1-2" mic	X	X	X	X	1.885	1.883-1.887	X	X	1
7	Steel Dowel	2-3 mic & Caliper	63/128	31/64 1/2	X	X	2.269	2.267-2.271	X	X	2
8	Grinder Wheel	Caliper	4 31/64	15/32 31/64	7/8	105/128 119/128	X	X	17/64	33/128 -35/128	3
9	Brass Sleeve	Caliper	1 31/128	29/128 33/128	1 3/16	23/128 25/128	X	X	X	X	2
10	Gray PVE	Caliper	2 7/32	27/128 29/128	1 59/128	57/128 15/32	2 7/32	27/128 29/128	X	X	3
11	Rubber Spacer	0-1" mic	0.878	.870-.884	X	X	X	X	0.232	.228-.236	2
12	Steel Dowel	1-2" mic	x	X	X	X	1.138	1.136-1.140	X	X	1
13	Aluminum Dowel	2-3 mic & Caliper	63/128	31/64 1/2	X	X	2.507	2.490-2.510	X	X	2
14	Large PVC	Caliper	5 3/64	1/32 1/16	4 1/2	61/128 67/128	3 53/64	13/16 - 107/128	X	X	3
15	Stainless Pipe	Caliper	1 1/4	31/128 33/128	1 5/32	19/128 21/128	X	X	X	X	2
											31

Living with Thermal Expansion and Contraction

Key Question: How do thermal expansion and contraction affect everyday objects?

Temperatures change all the time. In general, days are warmer than nights. Other places change temperature with the seasons.

Remember that the three main states of matter are: 1. Solid 2. Liquid. 3. Gas

Most matter expands when heated. Most matter contracts when cooled. This is true for every state of matter.

EXPANSION AND CONTRACTION OF SOLIDS

People who design structures such as buildings and bridges are very careful about the materials they use. They choose materials that will not break when temperatures change.

A building project will often require two or more materials. Designers should not choose materials that expand and contract in different ways. One material might expand faster than another material. If this happens, there could be damage to the structure.

Think about solid materials you use or see every day. A few examples of solids that expand and contract are

• metal frames around windows • hot-water pipes in homes • railroads • car engines

• metal lids on jars

What would happen if these materials were damaged?

You may think that a tooth does not change, but teeth can expand and contract like other materials. When you have a cavity, the dentist removes the decayed part and fills it in.

Some scientists work on making new filling materials. They want these fillings to expand and contract just like real teeth.

Building with Concrete

Engineers use steel rods to make concrete bridges and buildings stronger. The rods help support the concrete. The steel needs to expand and contract in the same way that the concrete does.

If the steel does not expand at the same rate as the concrete, the concrete can crack. Eventually the building could fall.

Bridges and sidewalks are built in sections. There are spaces between the sections called expansion joints (Figure 1). Expansion joints allow steel and concrete to expand without cracking.

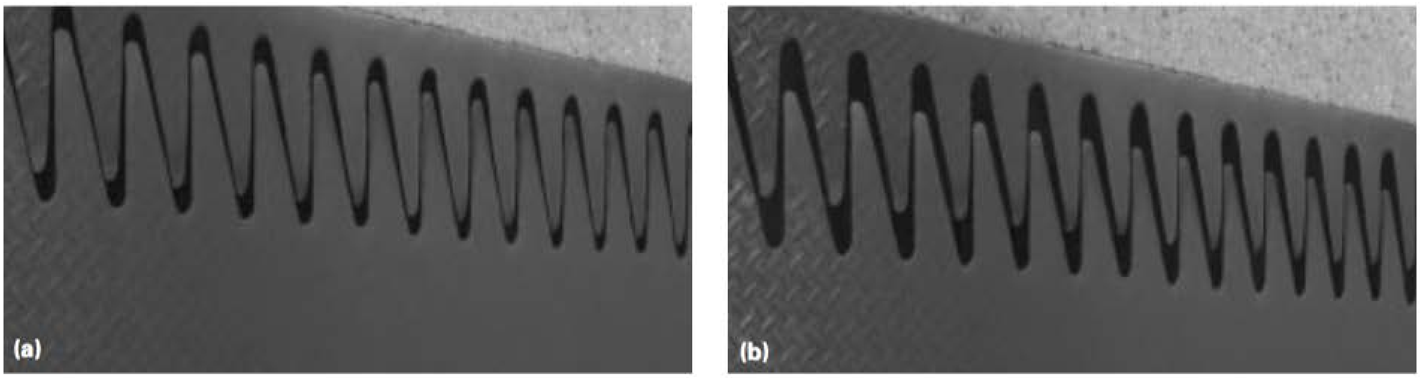

Figure 1 (a) The expansion joints narrow when bridge segments expand in hot weather. (b) Expansion joints in a bridge separate when the side-by-side segments of a bridge contract in cold weather.

Mackinac Bridge Facts:

What type of expansion joints are used on the Mackinac Bridge? How many?
There are two large finger joints at the towers to accommodate all the expansion of the suspended spans. There are 11 smaller finger joints and 5 sliding joints across the Mackinac Bridge. In addition, there are 13 expansion joints for the south viaduct spans - one for each of these simple spans. This adds up to a total of 31 total joints.

The bridge designer, David Steinman says in his book that over the whole length of the bridge, "a total of 27 feet of expansion had to be provided." (Source MDOT)

EXPANSION AND CONTRACTION OF GASES

Gases that are heated will expand in their containers. The energy of the gas particles will increase. The particles of warm gases hit the walls of the container more often. They also hit the walls harder.

If the walls of the container are flexible, the walls expand. If the walls are not flexible and cannot expand, then the pressure inside the container increases.

Think about gases you use or see every day. A few examples of gases that expand and contract are

• air in tires · air in a soccer ball · air in balloons (Figure 2) · air in an air mattress

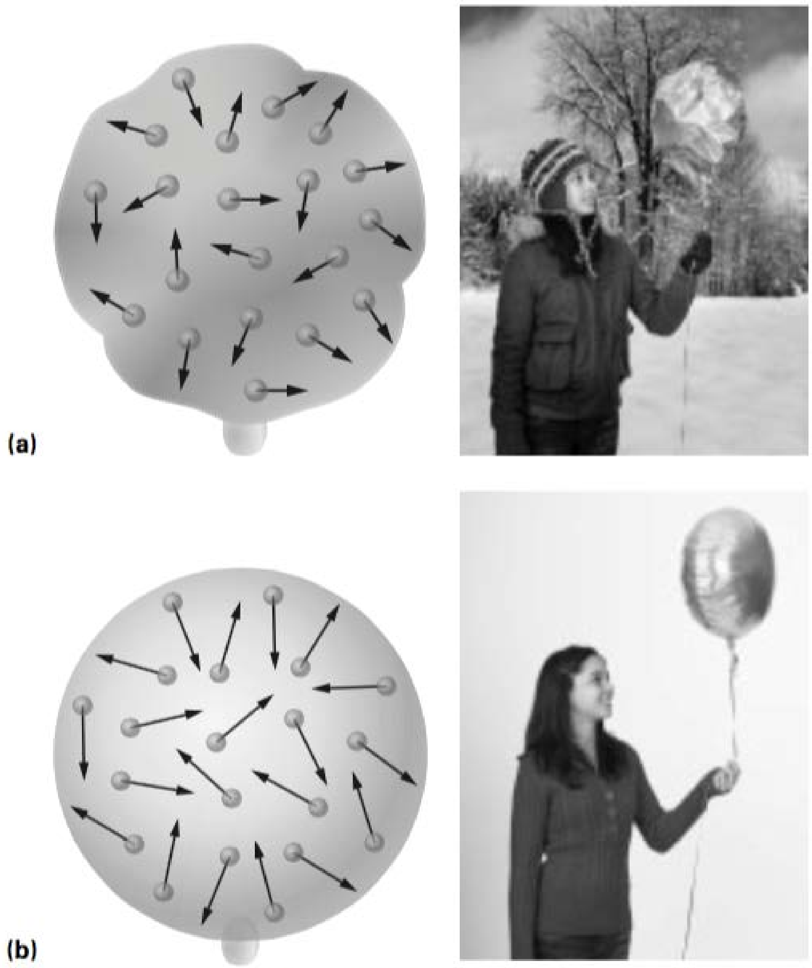

Figure 2 The helium gas in a balloon expands when you move a balloon from the cold outdoors to a warm room. (a) At a low temperature, the average kinetic energy of the particles in the balloon is low. The particles do not collide as often with the walls of the balloon, and hit the walls with less force. So, the balloon contracts. (b) As the temperature of the gas inside the balloon rises, the particles move faster and hit the wall of the balloon more often. So, the balloon expands.

What would happen if those materials did not expand and contract as they are meant to?

When cars and bicycles travel, their tires rub on the road. This makes the tires get hot. The air inside the tires will expand. If the tires are too full, they could burst.

Sports balls such as soccer balls are also filled with air. If you leave a soccer ball out in the cold, the air inside the ball will contract. The ball will get soft and it will become unusable.

EXPANSION AND CONTRACTION OF LIQUIDS

Think about liquid materials you use or see every day. A few examples of liquids that expand and contract are

• gasoline in cars (Figure 3a) • engine coolant • oceans and lakes • alcohol in thermometers (Figure 3b)

What would happen if these materials did not expand and contract as they are meant to?

In the last 100 years, the temperatures of oceans and lakes on Earth increased. Warmer oceans and lakes have a greater volume. When oceans have larger volumes, sea levels rise. If there is enough of an increase, coastal cities can flood.

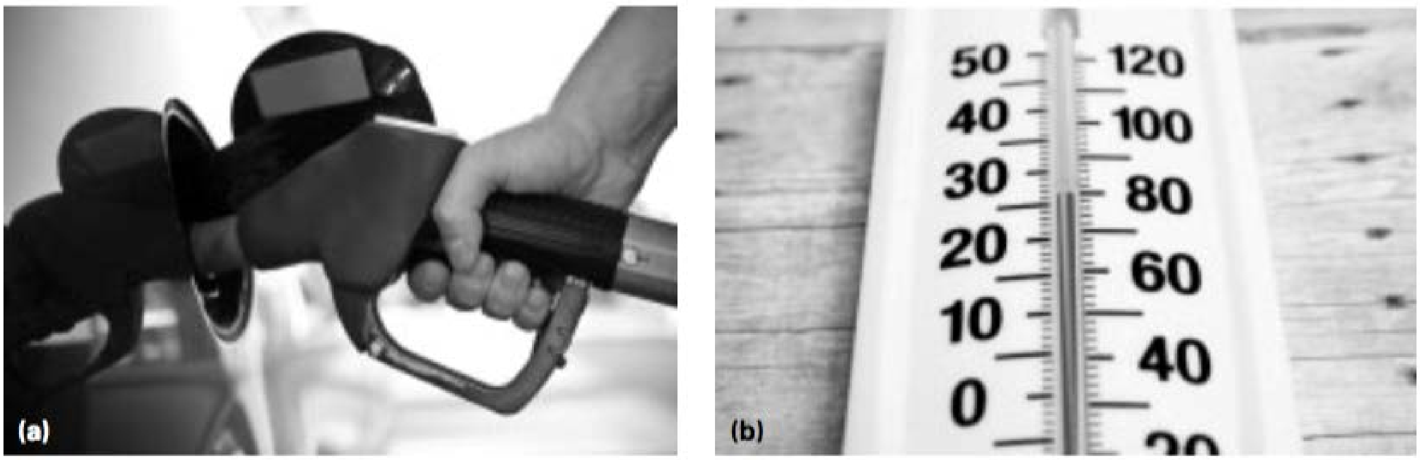

Figure 3 (a) Gasoline expands during hot weather. A full tank on a warm day could overflow. (b) The liquid in a thermometer expands and contracts as the air becomes warmer or cooler.

After a Soviet surface-to-air missile battery showdown with a USAF U-2 spy plane near the closed city of Sverdlovsk in 1960, the US government realised they needed a reconnaissance plane that could fly even higher – and outrun any missile and fighter launched against it.

The answer was the SR-71 Blackbird. It was closer to a spaceship than an aircraft, made of titanium to withstand the enormous temperatures from flying at 2,200mph (3,540kph). Its futuristic profile made it difficult to detect on radar – even the black paint used, full of radar-absorbing iron, helped hide it.

The top speed was limited by the engine temperature:
"The speed limit for the airplane ironically is nothing to do with the airplane, it's to do with the engines. Right in front of the engines was a temperature probe. When that temperature was around 427C (800F) that's as fast as we were allowed to go. The makers of the engine - Pratt & Whitney - would not warranty or guarantee anything beyond 427. After that all bets were off, the engine could come unglued or you could shed turbine blades."

The plane was purposely designed to leak fuel:
"The fuel tanks are the skin of the airplane. If you rap on this airplane, the fuel tank is on the other side. There's no internal fuel tanks. Because of the expansion and contraction cycles [due to heating and cooling of the aircraft at different speeds] it sometimes leaked and dropped from underneath the airplane. It was measured in Drops Per Minute – DPMs we called them – and maintenance used a stopwatch and counted them, and in certain locations on the aircraft there are acceptable and unacceptable Drips Per Minute."

Name____

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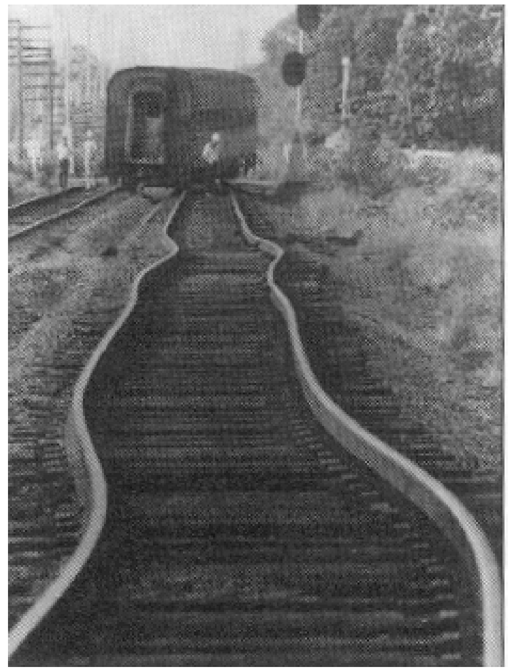
1.(5) This track was laid in February; the picture was taken in August 25. What do you think might have happened? Explain your answer.



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2. (2) Name two solid structures that expand and contract.

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3. (2) Name two liquids that expand and contract.

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4. (4) What would happen to a bridge that did not have expansion joints? Explain.

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5. (4) Correct this statement to make it true: "The particles in a material get bigger when heated."

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Name ______________________________

Item	Instrument	RT O.D.	Δ O.D.	% Exp/Cont	RT I.D.	Δ I.D.	% Exp/Cont	RT Length	Δ Length	% Exp/Cont	RT Thickness	Δ Thickness	% Exp/Cont	Measurements
Bearing H	0-1" mic				X	X	X	X	X		Center			2
Bearing C	1-2" mic				X	X	X	X	X		X	X	X	1
Copper Connector H	Caliper	X	X	X							X	X	X	2
Plastic Spacer C	0-1" Mic				X	X	X				X	X	X	2
Steel Sleeve H	1-2" mic	X	X	X	X	X	X				X	X	X	1
Steel Dowel C	2-3" Mic	X	X	X	X	X	X				X	X	X	1
Grinder Wheel C	Caliper							X	X		X	X	X	2
Brass Sleeve H	Caliper							X	X		X	X	X	2
Gray PVE C	Caliper				X	X	X				X	X	X	2
Rubber Spacer C	0-1" mic				X	X	X	X	X					2
Steel Dowel H	1-2" mic	X	X	X	X	X	X				X	X	X	1
Aluminum Dowel C	2-3 mic				X	X	X	X	X		X	X	X	1
Large PVC C	Caliper				X	X	X				X	X	X	2
Stainless Pipe H	Caliper	X	X	X				X	X		X	X	X	1
														22

Which material or item had the greatest amount of expansion? ______________________________

What was the % of expansion? __________________________

Which material or item had the greatest amount of contraction? ______________________________

What was the % of contraction? __________________________

Station	Item	Instrument	RT O.D.	Δ O.D.	% Exp/Cont	RT I.D.	Δ I.D.	% Exp/Cont	RT Length	Δ Length	% Exp/Cont	RT Thickness	Δ Thickness	% Exp/Cont	Measurements
1	Bearing H	0-1" mic				X	X	X	X	X	X	Center			2
2	Bearing C	1-2" mic				X	X	X	X	X	X	X	X	X	1
4	Copper Connector H	Caliper	X	X	X							X	X	X	2
5	Plastic Spacer C	0-1" Mic				X	X	X				X	X	X	2
6	Steel Sleeve H	1-2" mic	X	X	X	X	X	X				X	X	X	1
7	Steel Dowel C	2-3" Mic	X	X	X	X	X	X				X	X	X	1
8	Grinder Wheel C	Caliper							X	X	X	X	X	X	2
9	Brass Sleeve H	Caliper							X	X	X	X	X	X	2
10	Gray PVE C	Caliper				X	X	X				X	X	X	2
11	Rubber Spacer C	0-1" mic				X	X	X	X	X	X				2
12	Steel Dowel H	1-2" mic	X	X	X	X	X	X				X	X	X	1
13	Aluminum Dowel C	2-3 mic				X	X	X	X	X	X	X	X	X	1
14	Large PVC C	Caliper				X	X	X				X	X	X	2
15	Stainless Pipe H	Caliper							X	X	X	X	X	X	1
															22

Living with Thermal Expansion and Contraction

Key Question: How do thermal expansion and contraction affect everyday objects?

Temperatures change all the time. In general, days are warmer than nights. Other places change temperature with the seasons.

Remember that the three main states of matter are: 1. Solid 2. Liquid. 3. Gas

Most matter expands when heated. Most matter contracts when cooled. This is true for every state of matter.

EXPANSION AND CONTRACTION OF SOLIDS

People who design structures such as buildings and bridges are very careful about the materials they use. They choose materials that will not break when temperatures change.

A building project will often require two or more materials. Designers should not choose materials that expand and contract in different ways. One material might expand faster than another material. If this happens, there could be damage to the structure.

Think about solid materials you use or see every day. A few examples of solids that expand and contract are

• metal frames around windows • hot-water pipes in homes • railroads • car engines

• metal lids on jars

What would happen if these materials were damaged?

You may think that a tooth does not change, but teeth can expand and contract like other materials. When you have a cavity, the dentist removes the decayed part and fills it in.

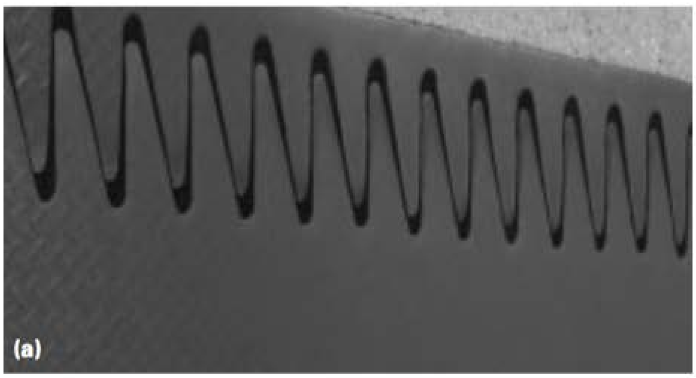
Some scientists work on making new filling materials. They want these fillings to expand and contract just like real teeth.

Building with Concrete

Engineers use steel rods to make concrete bridges and buildings stronger. The rods help support the concrete. The steel needs to expand and contract in the same way that the concrete does.

If the steel does not expand at the same rate as the concrete, the concrete can crack. Eventually the building could fall.

Bridges and sidewalks are built in sections. There are spaces between the sections called expansion joints (Figure 1). Expansion joints allow steel and concrete to expand without cracking.



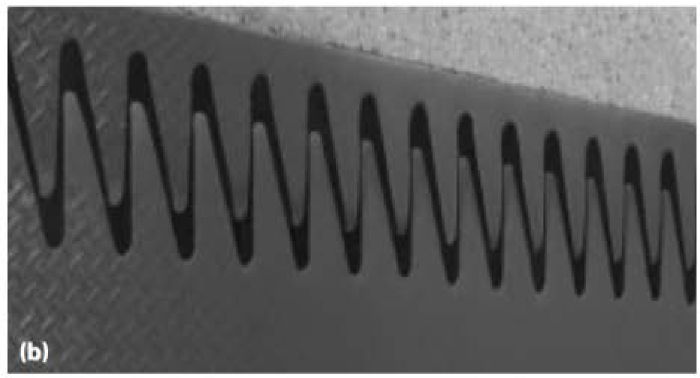


Figure 1 (a) The expansion joints narrow when bridge segments expand in hot weather. (b) Expansion joints in a bridge separate when the side-by-side segments of a bridge contract in cold weather.

Mackinac Bridge Facts:

What type of expansion joints are used on the Mackinac Bridge? How many?
There are two large finger joints at the towers to accommodate all the expansion of the suspended spans. There are 11 smaller finger joints and 5 sliding joints across the Mackinac Bridge. In addition, there are 13 expansion joints for the south viaduct spans - one for each of these simple spans. This adds up to a total of 31 total joints.

The bridge designer, David Steinman says in his book that over the whole length of the bridge, "a total of 27 feet of expansion had to be provided." (Source MDOT)

EXPANSION AND CONTRACTION OF GASES

Gases that are heated will expand in their containers. The energy of the gas particles will increase. The particles of warm gases hit the walls of the container more often. They also hit the walls harder.

If the walls of the container are flexible, the walls expand. If the walls are not flexible and cannot expand, then the pressure inside the container increases.

Think about gases you use or see every day. A few examples of gases that expand and contract are

• air in tires • air in a soccer ball • air in balloons (Figure 2) • air in an air mattress

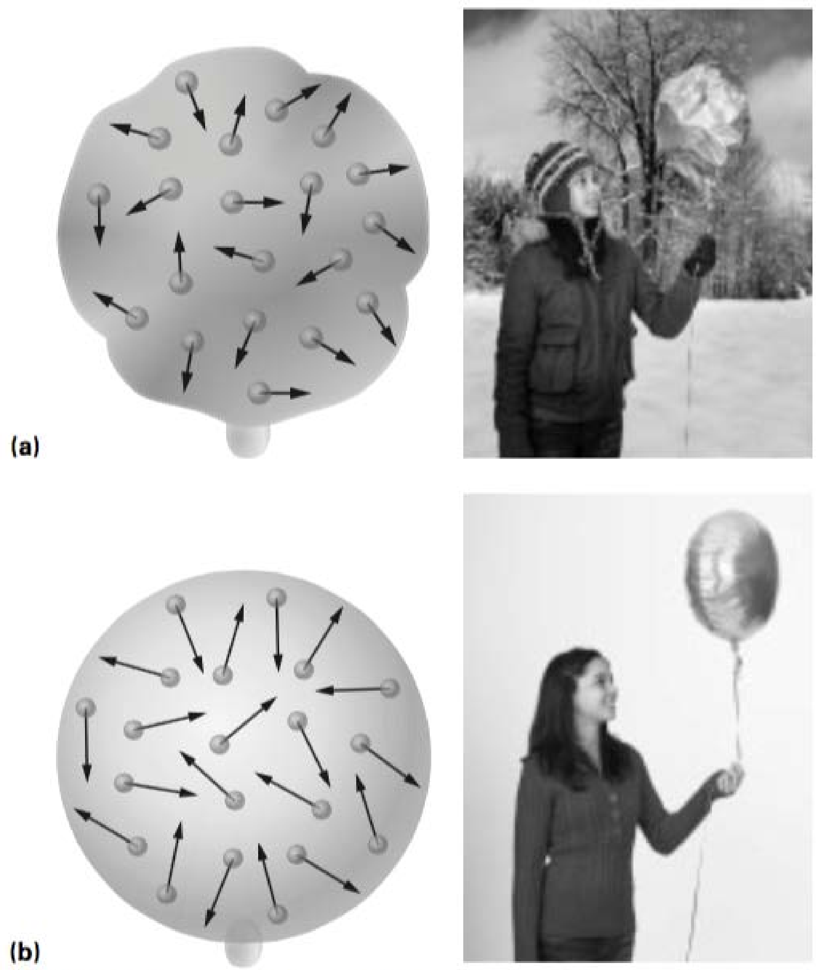


Figure 2 The helium gas in a balloon expands when you move a balloon from the cold outdoors to a warm room. (a) At a low temperature, the average kinetic energy of the particles in the balloon is low. The particles do not collide as often with the walls of the balloon, and hit the walls with less force. So, the balloon contracts. (b) As the temperature of the gas inside the balloon rises, the particles move faster and hit the wall of the balloon more often. So, the balloon expands.

What would happen if those materials did not expand and contract as they are meant to?

When cars and bicycles travel, their tires rub on the road. This makes the tires get hot. The air inside the tires will expand. If the tires are too full, they could burst.

Sports balls such as soccer balls are also filled with air. If you leave a soccer ball out in the cold, the air inside the ball will contract. The ball will get soft and it will become unusable.

EXPANSION AND CONTRACTION OF LIQUIDS

Think about liquid materials you use or see every day. A few examples of liquids that expand and contract are

• gasoline in cars (Figure 3a) · engine coolant · oceans and lakes · alcohol in thermometers (Figure 3b)

What would happen if these materials did not expand and contract as they are meant to?

In the last 100 years, the temperatures of oceans and lakes on Earth increased. Warmer oceans and lakes have a greater volume. When oceans have larger volumes, sea levels rise. If there is enough of an increase, coastal cities can flood.

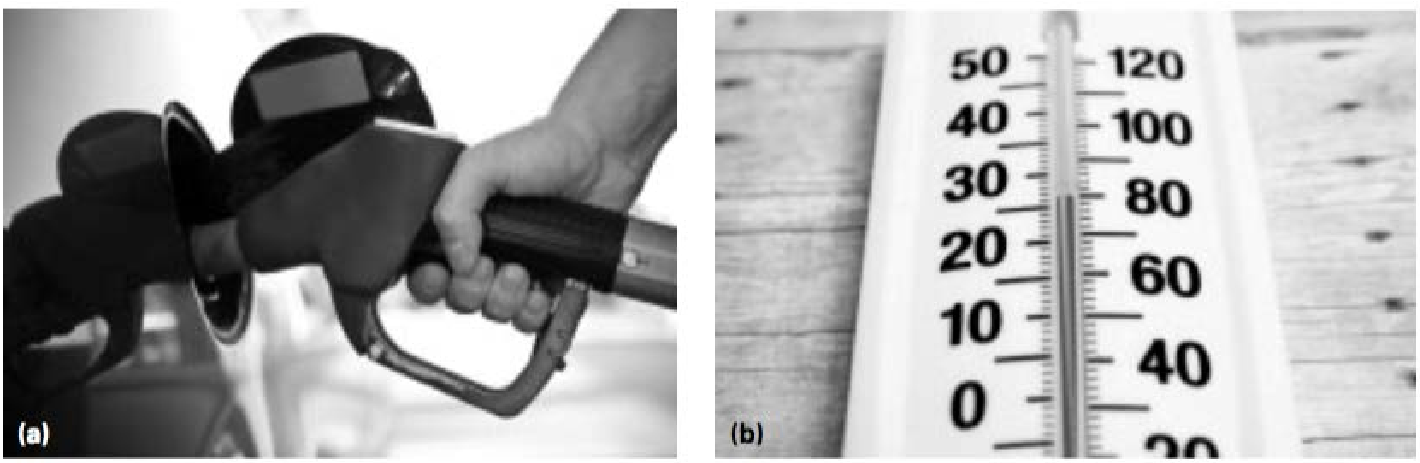


Figure 3 (a) Gasoline expands during hot weather. A full tank on a warm day could overflow. (b) The liquid in a thermometer expands and contracts as the air becomes warmer or cooler.

After a Soviet surface-to-air missile battery showdown with a USAF U-2 spy plane near the closed city of Sverdlovsk in 1960, the US government realised they needed a reconnaissance plane that could fly even higher – and outrun any missile and fighter launched against it.

The answer was the SR-71 Blackbird. It was closer to a spaceship than an aircraft, made of titanium to withstand the enormous temperatures from flying at 2,200mph (3,540kph). Its futuristic profile made it difficult to detect on radar – even the black paint used, full of radar-absorbing iron, helped hide it.

The top speed was limited by the engine temperature:

"The speed limit for the airplane ironically is nothing to do with the airplane, it's to do with the engines. Right in front of the engines was a temperature probe. When that temperature was around 427C (800F) that's as fast as we were allowed to go. The makers of the engine - Pratt & Whitney - would not warranty or guarantee anything beyond 427. After that all bets were off, the engine could come unglued or you could shed turbine blades."

The plane was purposely designed to leak fuel:

"The fuel tanks are the skin of the airplane. If you rap on this airplane, the fuel tank is on the other side. There's no internal fuel tanks. Because of the expansion and contraction cycles [due to heating and cooling of the aircraft at different speeds] it sometimes leaked and dropped from underneath the airplane. It was measured in Drops Per Minute – DPMs we called them – and maintenance used a stopwatch and counted them, and in certain locations on the aircraft there are acceptable and unacceptable Drips Per Minute."

Name_______________________________________

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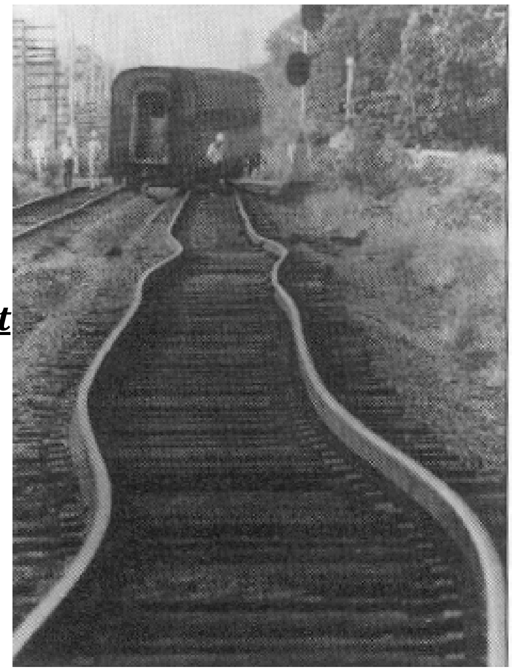
17

1.(5) This track was laid in February; the picture was taken in August 25. What do you think might have happened? Explain your answer.



When the track was laid in February, the temperature was cold and thus the temperature affect the particles to slow down and causing the material to contract or diminish in size. As the summer months approached, the temperature increase causing the particles within the material to speed up, moving faster and farther apart which then caused the material to expand. With out any expansion joints built within the track when it was laid in February, the track bent as it heated up.

2. (2) Name two solid structures that expand and contract.

• metal frames around windows • hot-water pipes in homes · railroads · car engines

3. (2) Name two liquids that expand and contract.

• gasoline in cars · engine coolant · oceans and lakes · alcohol in thermometers

4. (4) What would happen to a bridge that did not have expansion joints? Explain.

Bridges are built in sections with spaces between the sections called expansion joints. Expansion joints allow steel and concrete to expand without cracking. If the expansion joints were not in place, the bridge would buckle and crack and possibly collapse.

5. (4) Correct this statement to make it true: “The particles in a material get bigger when heated.”

False, the particles do not get bigger when heated. The particles actually vibrate at a faster rate when heated, as they vibrate, they move at a faster rate and move farther apart from each other. This vibration causes the material to expand.

Station	Item	Instrument	RT O.D.	Δ O.D.	% Exp/Cont	RT I.D.	Δ I.D.	% Exp/Cont	RT Length	Δ Length	% Exp/Cont	RT Thickness	Δ Thickness	% Exp/Cont	Measurements
1	Bearing H	0-1" mic	0.875"	0.888"	1.46%	X	X	X	X	X	X	Center.279"	.282"	1.77%	2
2	Bearing C	1-2" mic	1.125"	1.125"	0%	X	X	X	X	X	X	X	X	X	1
4	Copper Connector H	Caliper	X	X	X	1 11/32"	1 3/8"	2.27%	2 5/128"	2 7/128"	0.76%	X	X	X	2
5	Plastic Spacer C	0-1" Mic	.743"	.742"	-0.13%	X	X	X	.874"	.872"	0.45%	X	X	X	2
6	Steel Sleeve H	1-2" mic	X	X	X	X	X	X	1.884"	1.888"	0.21%	X	X	X	1
7	Steel Dowel C	2-3" Mic	X	X	X	X	X	X	2.268"	2.286"	0.785	X	X	X	1
8	Grinder Wheel C	Caliper	4 1/2"	4 1/2"	0%	7/8"	7/8"	0%	X	X	X	X	X	X	2
9	Brass Sleeve H	Caliper	1 1/4"	1 17/64"	1.23%	1 3/16"	1 19/128"	3.29% ?	X	X	X	X	X	X	2
10	Gray PVE C	Caliper	2 7/32"	2 31/128"	-1.06%	X	X	X	2 13/64"	2 27/128"	-0.35%	X	X	X	2
11	Rubber Spacer C	0-1" mic	.875"	.872"	-0.34%	X	X	X	X	X	X	.23"	.225"	-2.20%	2
12	Steel Dowel H	1-2" mic	X	X	X	X	X	X	1.136"	1.139"	2.60%	X	X	X	1
13	Aluminum Dowel C	2-3 mic	2.503"	2.502"	-0.03%	X	X	X	X	X	X	X	X	X	1
14	Large PVC C	Caliper	5 1/16"	5 1/16"	0%	X	X	X	3 27/32"	2 27/32"	0%	X	X	X	2
15	Stainless Pipe H	Caliper	1 1/4"	1 17/64"	1.23%	1 5/32"	1 11/64"	1.30%	X	X	X	X	X	X	1
															22
	Greatest Exp	Brass Sleeve	2.27%												
	Greates Cont	Rubber Spacer	2.20%												

Object	Length	Width	Height/Thickness	Inside Diameter	Outside Diameter
A (2" x 4")	1 1/32"	3 1/2"	1 1/2"	X	X
B (PVC Connector)	7/8"	X	X	19/32"	27/32"