BME2102：

Introduction to Biomechanics

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Labs (Syllabus)

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- Teaching and Learning Activities (TLAs)
  - Tutorial/Laboratory Sessions
    - Take place in classroom and laboratory, with assignments towards developing laboratory reports.
    - Labs: 3 hrs/week for 3 weeks
- Assessment Tasks/Activities (ATs)
  - Continuous Assessment: 40%
    - Laboratory Reports : 20%--3 reports to be submitted
- Assessment Rubrics

Assessment Task	Criterion	Excellent (A+, A, A-)	Good (B+, B, B-)	Fair (C+, C, C-)	Marginal (D)	Failure (F)
2. Laboratory Reports	Attendance of the lab/demo session; ABILITY to EXPLAIN the methodology and procedure and ANALYSE the lab data.	High	Significant	Moderate	Basic	Not even reaching marginal levels

Schedule

			15331	15332	15333	15334	15335	15336	15337
			C01	**T01**	**L01**	**L02**	**L03**	**L04**	**L05**
			17:00 - 18:50	10:00 - 11:50	09:00 - 11:50	09:00 - 11:50	14:00-16:50	09:00 - 11:50	09:00 - 11:50
			YEUNG	YEUNG	YEUNG	YEUNG	YEUNG	YEUNG	YEUNG
			LT-18	LT-18	Y1501	Y1501	Y1501	Y1501	Y1501
Week	Date	Instructor	DONG Lixin	DONG Lixin					
1	3/9	F	Lect 1						
2	10/9	F	Lect 2						
3	16/9	R							
	17/9	F	Lect 3						
4	23/9	R							
	24/9	F	Lect 4						
5	28/9	T			Lab				
	29/9	W					Lab		
	30/9	R						Lab	
	1/10	F	National Day						
6	5/10	T				Lab			
	7/10	R							Lab
	8/10	F	Lect 5	Tutorial 1					
7	15/10	F	In-class Test						
8	19/10	T			Lab				
	20/10	W					Lab		
	21/10	R						Lab	
	22/10	F	Lect 6						
9	26/10	T				Lab			
	28/10	R							Lab
	29/10	F	Lect 7						
10	4/11	R							
	5/11	F	Lect 8						
11	9/11	T			Lab				
	10/11	W					Lab		
	11/11	R						Lab	
	12/11	F	Lect 9						
12	16/11	T				Lab			
	18/11	R							Lab
	19/11	T	Lect 10	Tutorial 2					
13	26/11	F	Lect 11						

Lab Instructors

- Updates: AIMS and/or Canvas
- Labs (Students in HK must attend on campus)
  - Schedule:
    - L01 : wk 5, 8, 11 T (Y1501, B1667)
    - L02 : wk 6, 9, 12 T (Y1501, B1667)
    - L03 : wk 5, 8, 11 W (Y1501, B1667)
    - L04 : wk 5, 8, 11 R (Y1501, B1667)
    - L05 : wk 6, 9, 12 R (Y1501, B1667)
  - Y1501, Yeung Kin Man Academic Building
- TAs (Lab tutoring and report grading) – For questions about the lab and your report grades, please contact your TA.
  - **YU Zejie**: zejieyu2-c@my.cityu.edu.hk
  - **LIAO Junchen**: junchliao2-c@my.cityu.edu.hk
  - **CAO Hui**: huicao8-c@my.cityu.edu.hk
  - **WANG Shuideng**: sdwang8-c@my.cityu.edu.hk

Labs

- Lab 1： Tensile and 3-Point Bending Test
  - Lab. Sheet No.: BME2818
- Lab 2： 3D Printing of Biomedical Structures
  - Lab. Sheet No.: BME2820
- Lab 3： Electrophoresis
  - Lab. Sheet No.: BME2819
- Report due
  - For face-to-face sessions: one week after your session
  - For virtual sessions: one week after your session—the same as the face-to-face session you have registered
  - Deadlines setup with the submission folders in the Canvas for the reports do not mean your individual deadline but the deadline for the Lab held latest. Very important!!!
  - Late submissions: 1 Day -10%, 2 Days -25%, 3 Days -45%, 5 Days -75 %, 1 Week or longer -100%

Teams

Name	Lab Session	Team
AU Shun Yan Serene	L01	A
BABIC Marko	L01	A
CHENG Chit Yuen	L01	A
GUO Guihuan	L01	A
HUNG Chi Sing	L01	A
LAM Ka Long	L01	B
PAN Xinyu	L01	B
PANG Yan Yee	L01	B
PRIJADI Shannon Eugenia	L01	B
QU Qingao	L01	B
SIRIPAKDEECHAIKUL Apinant	L01	C
WANG Jiachen	L01	C
WONG Ka Hei	L01	C
ZHAO Zirui	L01	C
KO Yu Fei	L01	C
LI Zongze	L02	A
SHIM Yoonsue	L02	A
SIASAKUN Anchalee	L02	A
TSE Ting Kit	L02	A
YANG Shing Chun	L02	A
ZHANG Boyuan	L02	A

Name	Lab Session	Team
CHAN Hiu Lam	L03	A
CHONG Kin Tung	L03	A
CHU Hon Man Herman	L03	A
LAU Chun Yin	L03	A
LAW Long Hin Marvin	L03	A
LEE Ho Yin	L03	B
SIU Wai Hin	L03	B
SMAT Aidana	L03	B
WU Chiu Yan	L03	B
XING Jiazhen	L03	B

CHONG Hiu Kwan	L04	A
KHAN Abdul Raffay	L04	A
LAM Cheuk Fung	L04	A
LEUNG Shu Wah	L04	A
LI Tsz Hei	L04	B
LO Wai Ping	L04	B
SHIMA IYACU Nys Marlaine	L04	B
WONG Ching Yu	L04	B

Name	Lab Session	Team
CHENG Hoi Man	L05	A
HE Qinshu	L05	A
HO Yan Tung	L05	A
IP Chun Wang	L05	A
KONG Kin Man	L05	A
LAI Sin Yiu	L05	B
LEI Wang Kwo	L05	B
LEUNG Chun Hang	L05	B
LEUNG Hin Wai	L05	B
LUO Tsz Ki	L05	B
NG Chun Wai	L05	C
TSE Chin Wang	L05	C
WAN Ka Yu	L05	C
WONG Yuen Ching	L05	C
YU Cheuk Lam	L05	C

Schedules, Teams, Labs, and TAs

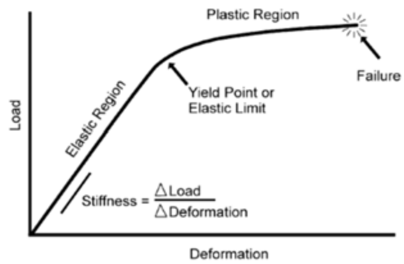
Week		Date	Time	YU Zejie	LIAO Junchen	CAO Hui	WANG Shuideng
5	T	28-Sep	09:00-11:50	L01A: Lab1	L01C: Lab2	L01B: Lab3	
	W	29-Sep	**14:00-16:50**	L03A: Lab1			L03B: Lab3
	R	30-Sep	09:00-11:50	L04A: Lab1			L04B: Lab3
6	T	5-Oct	09:00-11:50				L02A: Lab1
	R	7-Oct	09:00-11:50	L05A: Lab1	L05C: Lab2	L05B: Lab3	
8	T	19-Oct	09:00-11:50	L01B: Lab1	L01A: Lab2	L01C: Lab3	
	W	20-Oct	**14:00-16:50**		L03A: Lab2		L03B: Lab1
	R	21-Oct	09:00-11:50		L04A: Lab2		L04B: Lab1
9	T	26-Oct	09:00-11:50				L02A: Lab2
	R	28-Oct	09:00-11:50	L05B: Lab1	L05A: Lab2	L05C: Lab3	
11	T	9-Nov	09:00-11:50	L01C: Lab1	L01B: Lab2	L01A: Lab3	
	W	10-Nov	**14:00-16:50**			L03A: Lab3	L03B: Lab2
	R	11-Nov	09:00-11:50			L04A: Lab3	L04B: Lab2
12	T	16-Nov	09:00-11:50				L02A: Lab3
	R	18-Nov	09:00-11:50	L05C: Lab1	L05B: Lab2	L05A: Lab3	

Lab 1: Tensile and 3-D Bending Test

- Lab. Sheet No.: BME2818
- **Objectives**
  - The objective of this lab session is to allow the students to gain the basic understanding and experience on the tensile and bending of materials including an aluminum shaft and a bone. Elastic modulus, yield strength, ultimate strength, and failure strength will be determined from the stress-strain behaviors from the experiment.

Lab 1: Background

- Engineers study the mechanical behavior of a material by loading a small sample in a **materials testing system (MTS)**, which simultaneously measures the force and displacement of the material as it is deformed at various rates.
- The resulting graph is called a **load-deformation curve**, which can be converted with other measurements to obtain a **stress–strain graph**.



Lab 1: Background

- Load-deformation graphs have several variables and regions of interest.
  - The elastic region is the initial linear region of the graph where the slope corresponds to the stiffness or Young's modulus of elasticity of the material. Stiffness or Young's modulus is defined as the ratio of stress to strain in the elastic region of the curve, but is often approximated by the ratio of load to deformation (ignoring the change in dimension of the material).
  - If the test were stopped within the elastic region the material would return to its initial shape. If the material were perfectly elastic, the force at a given deformation during restitution (unloading) would be the same as in loading.

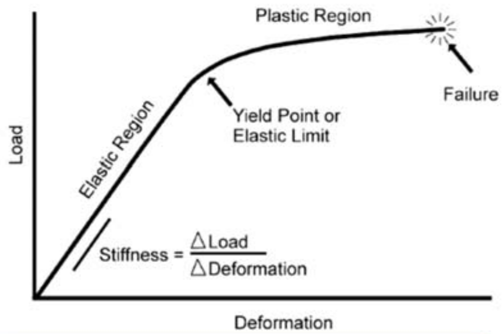
Lab 1: Background

– If the material were perfectly elastic, the force at a given deformation during restitution (unloading) would be the same as in loading.
– Biological tissues are however not like a perfectly elastic spring, so they lose some of the energy in restitution that was stored in them during deformation.

Lab 1: Background

– Beyond the linear region is the **plastic region**, where increases in deformation occur with minimal and nonlinear changes in load. The **yield point** or **elastic limit** is the point on the graph separating the elastic and plastic regions. When the material is deformed beyond the yield point the material will not return to its initial dimensions.

– In biological materials, normal physiological loading occurs within the elastic region, and deformations near and beyond the elastic limit are associated with microstructural damage to the tissue. Another important variable calculated from these measurements is the **mechanical strength** of the material.



Lab 1: Background

- The **mechanical strength** of a material is the measurement of the maximum force or total mechanical energy the material can absorb before failure. The energy absorbed and mechanical work done on the material can be measured by the area under the load deformation graph.
- Within the plastic region, the pattern of failure of the material can vary, and the definition of failure can vary based on the interest of the research.
- Conditioning and rehabilitation professionals might be interested in the **yield strength** (force at the end of the elastic region) of healthy and healing ligaments. Sports medicine professionals may be more interested in the **ultimate strength** that is the largest force or stress the material can withstand.

Lab 1: Background

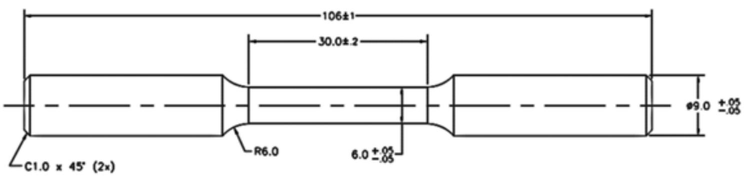
- Sometimes it is of interest to know the total amount of strain energy the material will absorb before it breaks because of the residual forces that remain after ultimate strength. This is **failure strength** and represents how much total loading the material can absorb before it is broken. The mechanical strengths of materials will be identified by their relevant adjective (yield, ultimate, or failure).

Lab 1: What we will do in the lab

- To test the material in tensile and bending, the proper test procedures are needed. (Read the Manual: **BME2818a Tensile.docx** and **BME2818b 3-Point Bending.docx**—the same contents as in the following slides)
- It involves mounting a shaft or a bone into the testing machine, applying loads incrementally and measuring both the applied force and the corresponding deformation. (Watch the Videos under the folders **BME2818a Tensile** and **BME2818b 3-Point Bending**, the same videos have been inserted into the following slides)
- Using the appropriate formulae, relationships, the measured dimensions, and testing results (**BME2818a Testing Results Tensile.xlsx** and **BME2818b Testing Results 3-Point Bending Fresh Bone.xlsx**, and **BME2818b Testing Results 3-Point Bending Dry Bone.xlsx**), you can determine the stress and strain on the specimen.
- Then, you can plot the force vs. deformation, and stress vs. strain curves from which one can find the material properties previously mentioned.

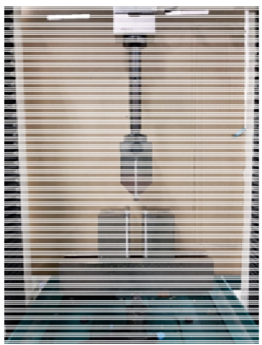
Lab 1: Specimens and Apparatuses

- Tensile testing specimens:
- Solid aluminum shaft



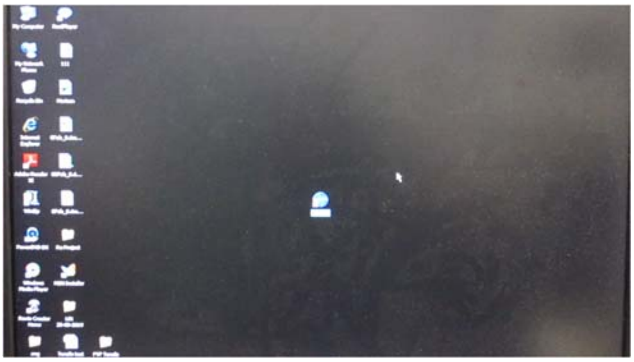
- Bone (Outer Diameter: ~ 3.5 mm, Inner Diameter: ~ 1.9 mm, a fresh one and a dry one (100°C, 1 hour)
- Oven
- Vernier Caliper
- Tinius Olsen H50KT Test System
- Tensile test fixture
- 3-Point bending test fixture
- Safety glasses (if on site)


Tensile test fixture

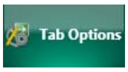

3-Point bending test fixture

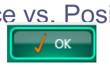
Lab 1a: Experimental Procedures for Tensile Test

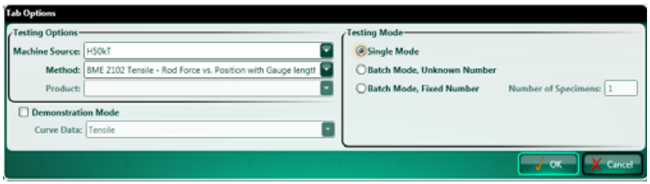
- 1. Start up
  - Power on, **Computer**, **Tinius Olsen H50KT testing system**.
  - Computer User name: Administrator
  - Password: labclass



- 2. Setting the **Computer** to conduct the test.
  - a. Double click 

 icon in desktop.
  - b. Click 

 icon in the system.
  - c. Select Method “BME 2102 Tensile – Rod Force vs. Position with Gauge length” then click 



Lab 1a: Install the tensile test fixture

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- d. Install or change the fixtures according the testing method.
  - ➢ Install the tensile test fixture: upper.

  - ➢ Install the tensile test fixture: lower

Lab 1a: Experimental Procedures for Tensile Test

- e. Select Test & Recall icon on the top.
- f. Zero the Force click Ø in Force 0 N

Lab 1a: Experimental Procedures for Tensile Test

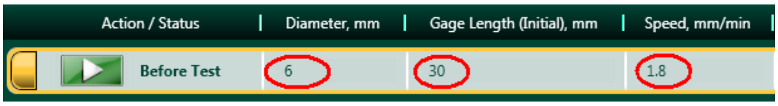
- g. Measure the diameter of the specimen.

- h. Fix the specimen on the fixture.

Lab 1a: Experimental Procedures for Tensile Test

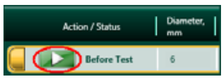
- i. Click and hold the or icon until the force around 100N.
- j. Zero the Force click ∅ in

- k. Input the specimen Diameter, Gauge length and Speed in



Lab 1a: Experimental Procedures for Tensile Test

- 3. Performing the test.
  - a. Click the start Horizon software



  - b. At the end of the test specimen broken.
  - c. Click

    to accept this test (save the tested data in the computer)
  - d. Export the raw data into the computer – mouse right click in which tested you want to export the select “This specimen”

  - e. Click “OK”

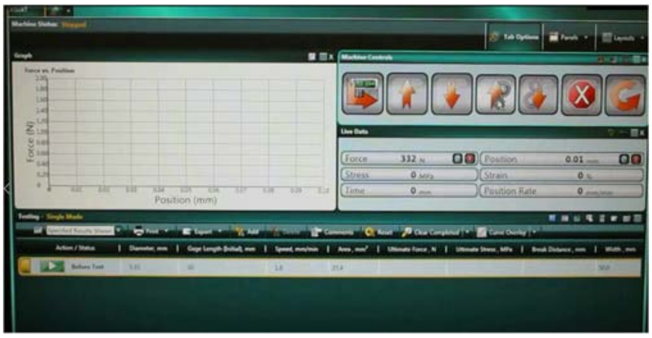
    file export Successful.
  - f. Change the file name in the path.

Lab 1a: Experimental Procedures for Tensile Test

Specimen before the test

Specimen after the test

Testing

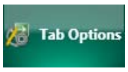


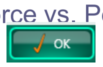
Lab 1a: Experimental Procedures for Tensile Test

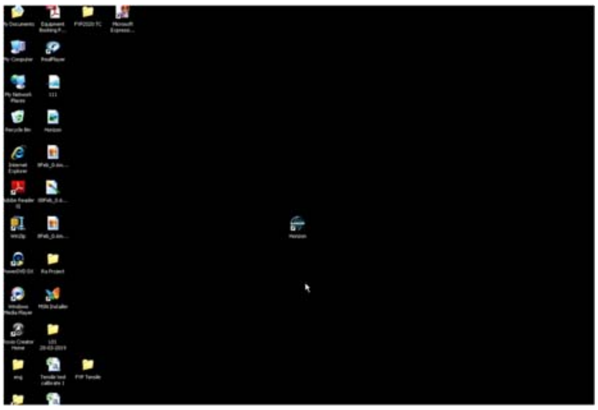
- 4. Conducting **More tests**
  - Go to step 2-h.
- 5. Finished all the test
  - Select close for Horizon software.
  - Switch off the **Tinius Olsen H50KT testing system**

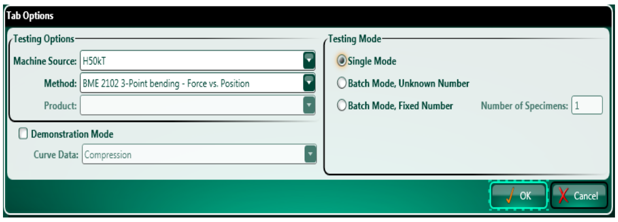
Lab 1b: Experimental Procedures for 3-Point Bending Test

- 1. Start up
  - Power on, **Computer**, **Tinius Olsen H50KT testing system**.
  - Computer User name: Administrator
  - Password: labclass
- 2. Setting the **Computer** to conduct the test.
  - a. Double click 

icon in desktop.
  - b. Click 

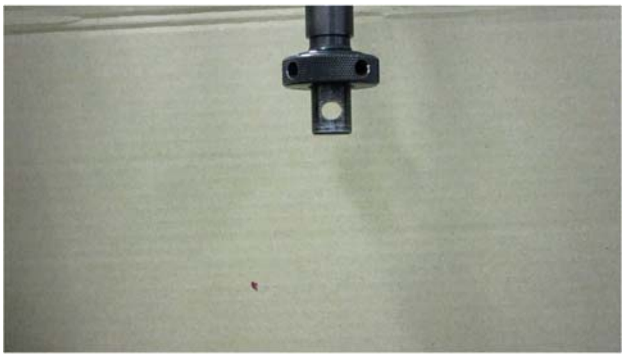
icon in the system.
  - c. Select Method "BME 2102 3-Point bending – Force vs. Position" then click 





Lab 1b: Experimental Procedures for 3-Point Bending Test

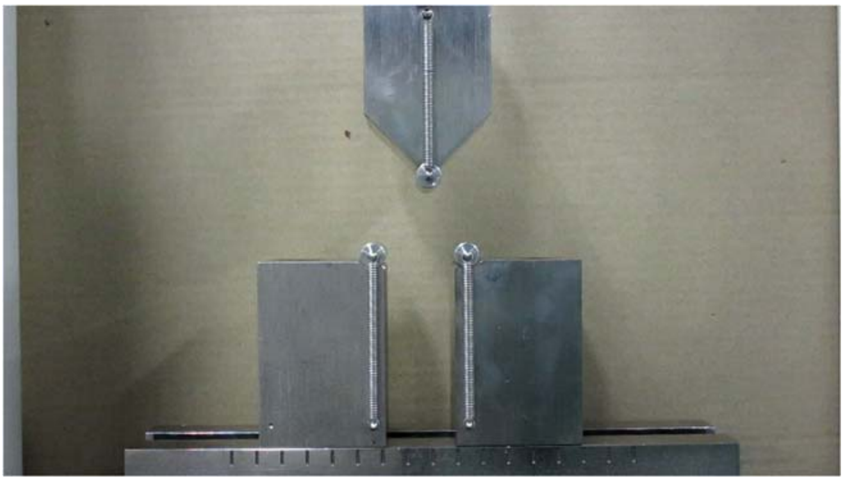
- d. Install or change the fixtures according the testing method.
  - ➢ Install loading nose



  - ➢ Install support span

Lab 1b: Experimental Procedures for 3-Point Bending Test

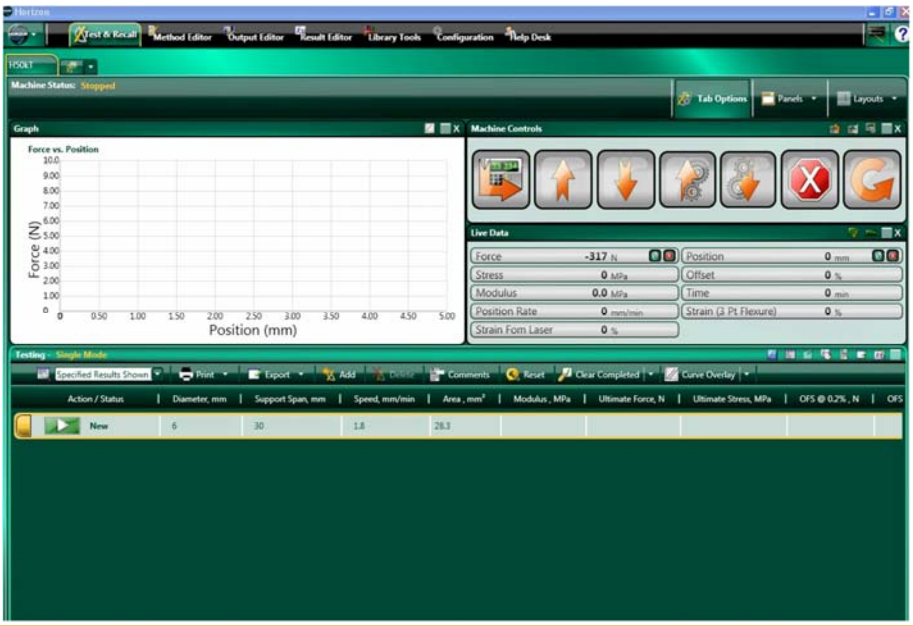
– e. Adjust the distance of the support span and align the loading nose.



Lab 1b: Experimental Procedures for 3-Point Bending Test

– f. Select Test & Recall icon on the top.

– g. Zero the Force click Ø in Force 0 N



Lab 1b: Experimental Procedures for 3-Point Bending Test

– i. Measure the fresh specimen diameter

Lab 1b: Experimental Procedures for 3-Point Bending Test

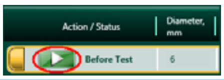
– i. Put the fresh specimen on the support span

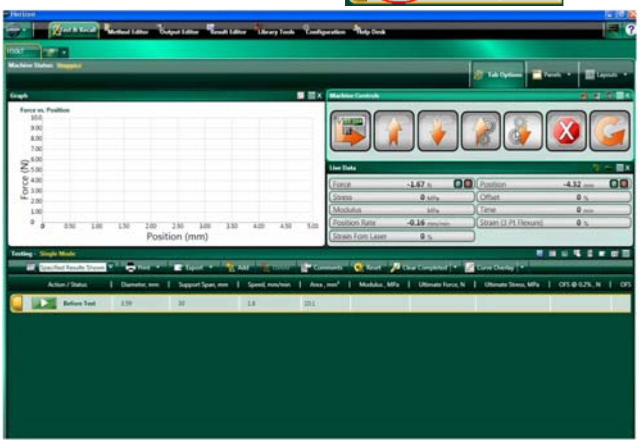
Lab 1a: Experimental Procedures for Tensile Test

- k. Click and hold the or icon until the crosshead fixture touching the specimen.
- l. Zero the Force click in 

- m. Input the specimen Diameter, Support Span and Speed in

Lab 1a: Experimental Procedures for Tensile Test

- 3. Performing the test.
  - a. Click the start Horizon software 

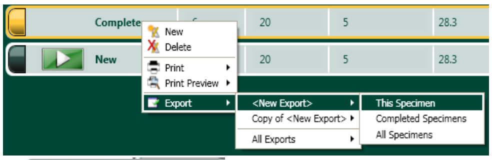


  - b. At the end of the test (*i.e.,* when the specimen breaks or compression end point are reached), go to c.
  - c. In the Horizon software return the crosshead click “Yes”

Lab 1a: Experimental Procedures for Tensile Test

- 3. Performing the test.
  - c. Click 

 to accept this test (save the tested data in the computer)
  - d. Export the raw data into the computer – mouse right click in which tested you want to export the select "This specimen"



  - e. Click "OK" 

 file export Successful.
  - f. Change the file name in the path.
  - g. Measure the wall thickness of the specimen.

Lab 1b: Experimental Procedures for Tensile Test

Fresh bone specimen after the test

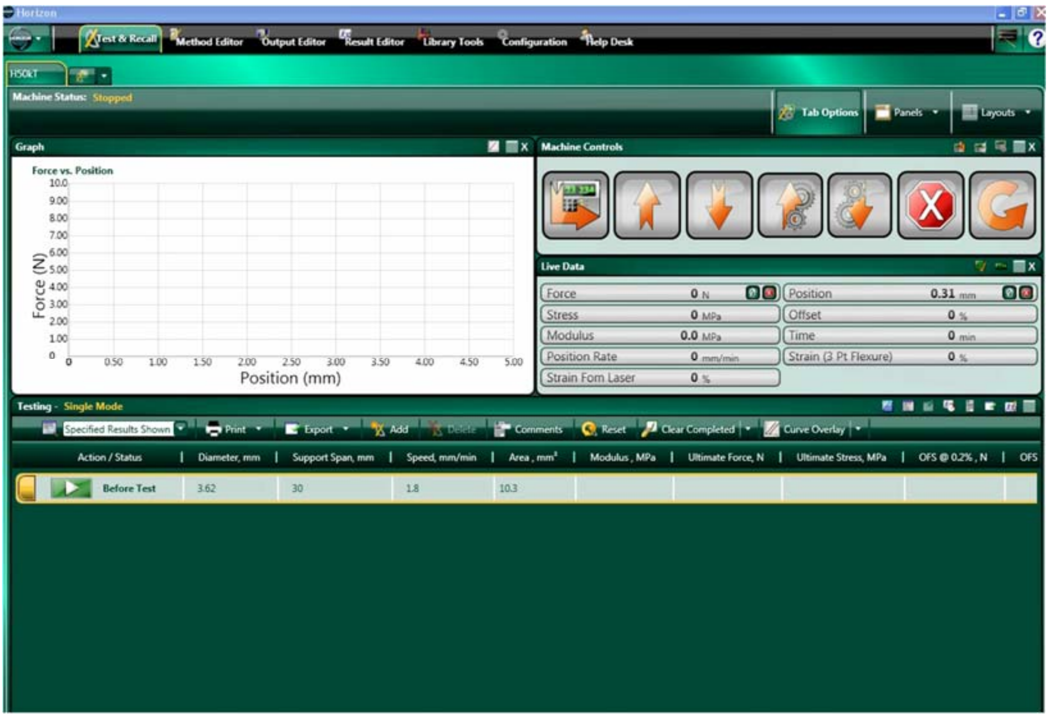
Lab 1a: Experimental Procedures for Tensile Test

- 4. Conducting **More tests**
  - Go to step 2-h.
- 5. Finished all the test
  - Select close for Horizon software.
  - Switch off the **Tinius Olsen H50KT testing system**

Lab 1b: Measure the dry specimen diameter

Lab 1b: Put the dry specimen on the support span

Lab 1b: Testing dry specimen



Lab 1b: Measure the dry specimen thickness

Lab 1b: Experimental Procedures for Tensile Test

Fresh bone specimen after the test

Lab 1: Data Analysis and Discussion

- 1. Plot the graphs for each sample:
  - Load vs. deformation/deflection using the testing results
  - Face-to-face sessions: use your own data
  - Virtual sessions: use **BME2818a Testing Results Tensile.xlsx**, **BME2818b Testing Results 3-Point Bending Fresh Bone.xlsx**, and **BME2818b Testing Results 3-Point Bending Dry Bone.xlsx**.
  - Stress vs. strain (Obtain the geometric sizes from the videos)
  - There should be 6 graphs in all, two for each specimen.
- 2. From the graphs determine:
  - Elastic modulus, Flexural strength, Ultimate strength, and Failure strength.
- 3. Compare and discuss the materials properties obtained from all three specimens based on the relation between stresses and strains.

Lab 1: Data Analysis and Discussion

- 4. Analyze experimental error, explain unusual data, describe circumstance which might induce error and unusual data, and report phenomena that you consider important.
- 5. Suggest possible improvement of this test if necessary.

Lab 1: Report

- The report shall contain:
  - A cover sheet (with also a Table of Contents)
  - Objectives
  - Procedures (describe with your own words)
  - Lab results
  - Data analysis and discussions (check individual lab sheet for relevant suggestions)
  - Conclusions
  - References, if any
- Note: Please write the lab reports in your own words.

Lab 2: 3D Printing of Biomedical Structures

- Lab. Sheet No.: BME2820
- **Objectives**
  - Get familiar with the general procedure for physical model fabrication using 3D printing (3DP) method;
  - Be able to describe basic operations of 3D printing process, namely Fused Filament Fabrication (FFF), through hands-on activities on a bone model (for both horizontal and vertical printing).

Lab 2: 3D Printing of Biomedical Structures

- Introduction
  - 3D Printing (3DP) refers to a class of manufacturing processes that build a part by incrementally adding materials layer by layer. Based on an input stereolithography (STL) file, a triangle faceted model of the target object for printing, the model is sliced into a series of horizontal cross-sectional thin layers. A 3D printing machine then builds the physical prototype model layer by layer starting from the bottom layer. This is an "additive" process joining layers of plastic, metal, paper or wax material to form the resulting physical prototype model. In this hands-on activity, we introduce basic operations on one popular 3D printing processes, namely Fused Filament Fabrication (FFF) from Ultimaker 3D printer.

Lab 2: 3D Printing of Biomedical Structures

- Introduction
  - An FFF machine, on the other hand, produces a prototype model using various other materials, such as Polylactic acid(PLA) /Acrylonitrile butadiene styrene(ABS) /Polycarbonate(PC) /Polypropylene(PP) /Polyamide(Nylon). Similar to any other 3D printing processes, it builds a part layer by layer. The FFF head heats up the material from its original form of solid wire to a semi-liquid state and extrudes the material on top of the previous layer through a nozzle to form a new layer.

Lab 2: 3D Printing of Biomedical Structures

- Apparatus and Software
  - Modeler: Ultimaker-3 3D Printer
  - Modeling material: PLA
  - Support material: PLA
  - Nozzle diameter: 0.40 mm
  - Layer resolution: 0.1 mm
  - 3D printing Software: Ultimaker Cura

Lab 2: 3D Printing of Biomedical Structures

- Procedures
  - This set of hands-on activities consists of two sessions, one introducing the basic operations on 3D printing software and another one for getting familiar operation with popular 3D printing method, namely FFF available from the Product Testing and Inspection Laboratory. The objectives for the hands-on activities are briefly highlighted as follows. Further details can be found from the accompany hands-on documents.

Lab 2: 3D Printing of Biomedical Structures

- ***Hands-on Activity No. 1.*** Basic operations on 3D printing software. Following this hands-on activity, you will be able to get familiar prepare 3D printing toolpath through the exercises. You will work on the print client computer to
  - 1. Import STL format model file
  - 2. Orientate the model
  - 3. Scaling the model
  - 4. Specify print nozzle size and printing material
  - 5. Set printing parameters
  - 6. Slicing and Toolpath generation
  - 7. Toolpath inspection and adjustment
  - 8. Save and export toolpath (g-code file)

Lab 2: 3D Printing of Biomedical Structures

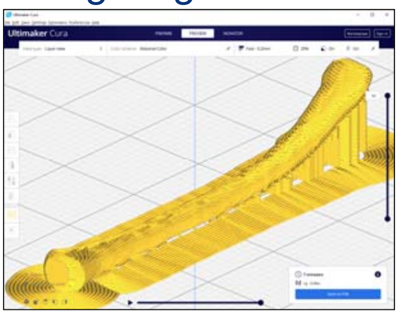
- ***Hands-on Activity No. 2.*** Get familiar with the general procedure and for physical model fabrication using 3D printing (3DP) process, Fused Filament Fabrication (FFF). Main procedure involved:
  - 1. Clean and check residual on the build plate surface
  - 2. Loading material (filament spool)
  - 3. Uploading g-code file
  - 4. Start printing model
  - 5. Monitor primary layers material adhere on the build plate
  - 6. Printing end, wait for build plate temperature lower down
  - 7. Take off build plate and remove printed model

Lab 2: 3D Printing of Biomedical Structures

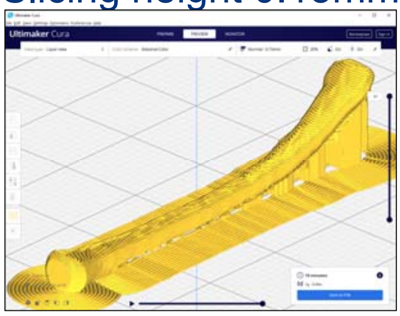
- Watch the videos:
  - wrkflwONcomp_Hi.mp4
  - 3dp_v1_dwnSiz.mp4
- Read the manual
  - bme2820_OP_manl_v1.pdf

Model printed in various slicing height

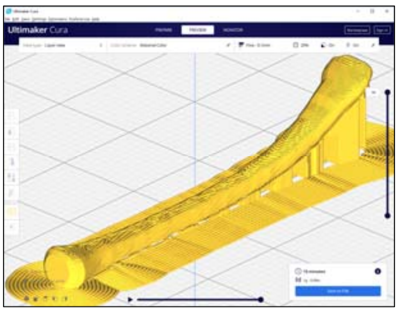
Slicing height 0.20mm



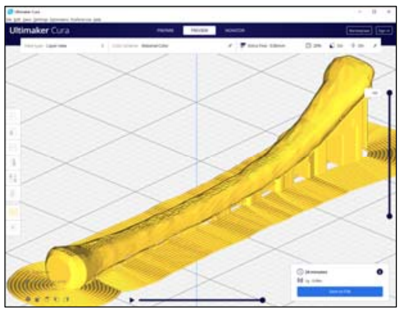
Slicing height 0.15mm



Slicing height 0.10mm

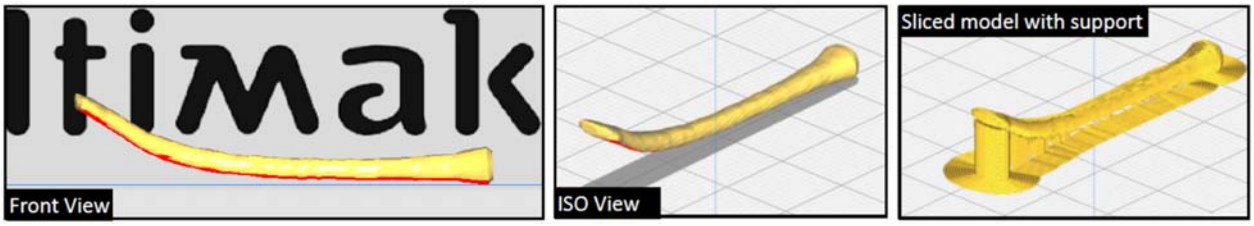


Slicing height 0.06mm



Estimated Build Time and Material Consumption in Various Orientation

Orientation #1

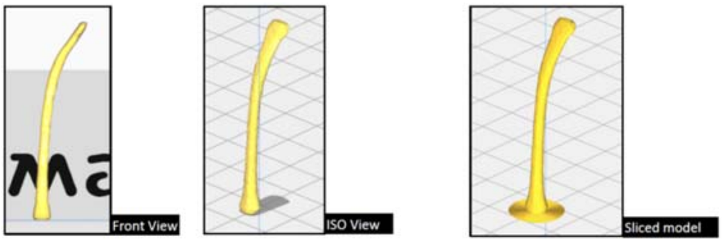


- Major printing parameters
  - Infill: 10%
  - Support: Enabled
  - Adhesion brim: Enabled

Slicing height (mm)	Building time (min)	Material consumption	
		Weight(g)	Length(m)
0.2	7	1.0	0.09
0.15	9	1.0	0.09
0.1	15	1.0	0.09
0.06	24	1.0	0.09

Estimated Build Time and Material Consumption in Various Orientation

Orientation #2



- Major printing parameters
  - Infill: 10%
  - Support: Disabled
  - Adhesion brim: Enabled

Slicing height (mm)	Building time (min)	Material consumption	
		Weight(g)	Length(m)
0.2	14	<1.0	0.06
0.15	19	<1.0	0.06
0.1	20	<1.0	0.06
0.06	24	<1.0	0.06

Estimated Build Time and Material Consumption in Various Orientation

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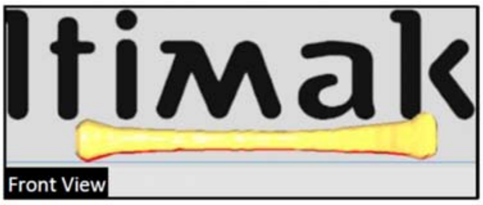
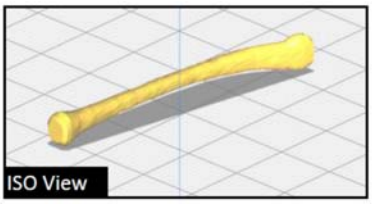
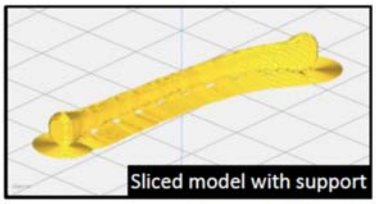
Orientation #3







- Major printing parameters
  - Infill: 10%
  - Support: Enabled
  - Adhesion brim: Enabled

Slicing height (mm)	Building time (min)	Material consumption	
		Weight(g)	Length(m)
0.2	5	1	0.08
0.15	7	1	0.08
0.1	11	1	0.08
0.06	17	1	0.08

Estimated Build Time and Material Consumption in Various Orientation

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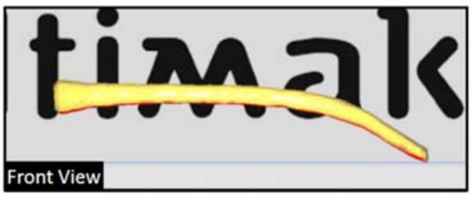
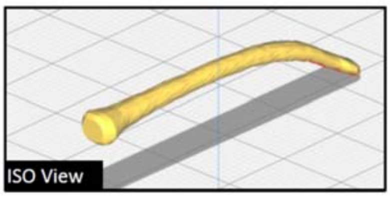
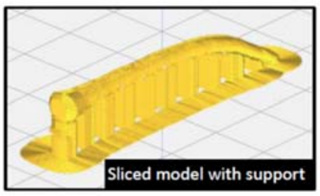
Orientation #4







- Major printing parameters
  - Infill: 10%
  - Support: Enabled
  - Adhesion brim: Enabled

Slicing height (mm)	Building time (min)	Material consumption	
		Weight(g)	Length(m)
0.2	7	1	0.11
0.15	9	1	0.11
0.1	16	1	0.11
0.06	26	1	0.11

Model printed in various slicing height

Slicing height: 0.20mm 0.15mm 0.10mm 0.06mm

Model printed in various slicing height

Slicing height: 0.20mm 0.15mm 0.10mm 0.06mm

Model printed in various slicing height

Slicing height: 0.20mm 0.15mm 0.10mm 0.06mm

Lab 2: 3D Printing of Biomedical Structures

- Report
  - In your report, briefly summarize the lab objective, tasks completed, brief procedures involved, results obtained, and comments on the following:
  - General procedure on 3D printer.
  - Prepare 3D printing toolpath file.
  - Fused Filament Fabrication (FFF) process.
  - Key parameters for FFF model slicing, path and support generation.
  - Factors affecting FFF part building time and surface finishing.

Lab 3

- Lab 3： Electrophoresis
  - Lab. Sheet No.: BME2819

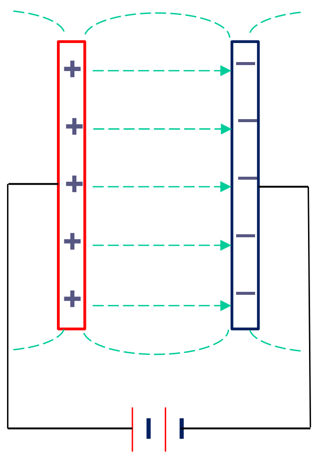
Electrostatic Forces

- Let us consider the electrostatic force between two parallel plates. Let *A* denote the surface area of the plates, and let *x* be the separation distance. Assume *x* is small relative to the dimensions of the plates. The capacitance is given by

$$C = \varepsilon \frac{A}{x}$$

where ε is the permittivity of the dielectric material separating the plates. The capacitance relates a voltage *U* that is applied to the plates to the charge Q that is accumulated on each plate: $Q = CU$. The electrostatic co-energy stored in the capacitor can be expressed by

$$W = \frac{1}{2} C U^2$$



Electrostatic Forces

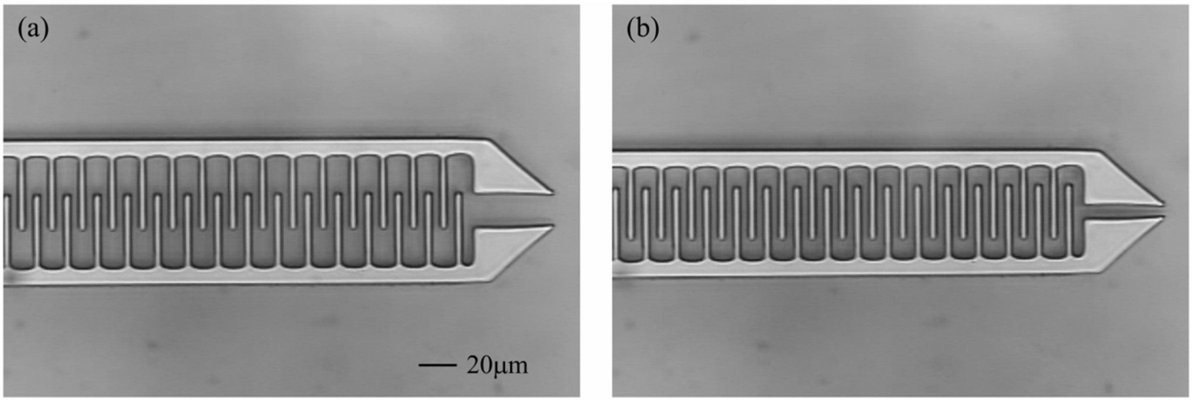
- The attractive force between the plates is computed as $F = -dW/dx$.
- In the case of constant voltage

$$F_U = \frac{\varepsilon A U^2}{2x^2}$$

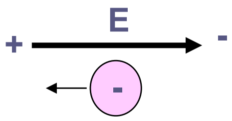
- In the case of constant charge:

$$F_Q = \frac{Q^2}{2\varepsilon A}$$

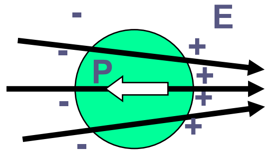
Electrostatic Gripper



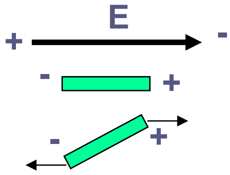
Motion Generate by Electrostatic Forces



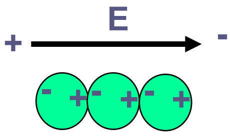
(a) Electrophoresis



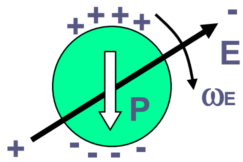
(b) Dielectrophoresis



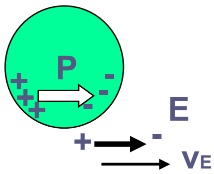
(c) Orientation force



(d) Pearl chain forming



(e) Electrorotation



(f) Travelling-wave drive

Lab 3: Electrophoresis

- Lab. Sheet No.: BME2819
- **Objectives**
  - The objective of this lab session is to allow the students to gain the basic understanding and experience on the electrophoresis from the experiment.
  - In the test, food coloring molecules (Federal Food, Drug, and Cosmetic (FD&C) Food Dyes Blue-1, Red-40, and Yellow-5), which are several orders of magnitude smaller than typical proteins and DNA, are used as specimens to show the electrophoretic effects by electric fields.
  - Terminal velocities of dyes are measured as a function of the electric potential applied along strips.

Lab 3: Background

- Electrophoresis is a general term that describes the migration and separation of charged particles (ions) under the influence of an electric field.
- An electrophoretic system consists of two electrodes of opposite charge (anode, cathode), connected by a conducting medium called an electrolyte.
- Electrophoresis is primarily used to spatially separate mixtures containing different chemical compounds, i.e., different species of molecules such as DNA and RNA, proteins, or other biological samples according to their size.

Lab 3: Background

- Beginning with its discovery in 1807 (and subsequent early development in the 1930s), electrokinetic phenomena have long been harnessed as a method of mixture separation in a variety of fields and subdisciplines.
- Nowadays, such phenomena have been collectively organized under the term “electrophoresis” and have become ubiquitous in the biosciences; they are utilized in a host of disparate applications, ranging from protein analysis in blood samples to DNA testing and identification.
- It is to these continued contributions to the clinical and forensic sciences, along with recent advances in the pharmaceutical and life sciences, that electrophoretic analysis owes its rebirth and surge in popularity.

Lab 3: Specimens and Apparatuses

- Specimen: FD&C Food Dyes Blue-1, Red-40, and Yellow-5
- Mini Horizontal Gel Electrophoresis System (MT-108)
- Mini Pro 300V / 500V Power Supply
- Micropipette
- Whatman 3 MM chromatographic paper
- Ruler

(a) Electrophoresis System

(b) Power Supply

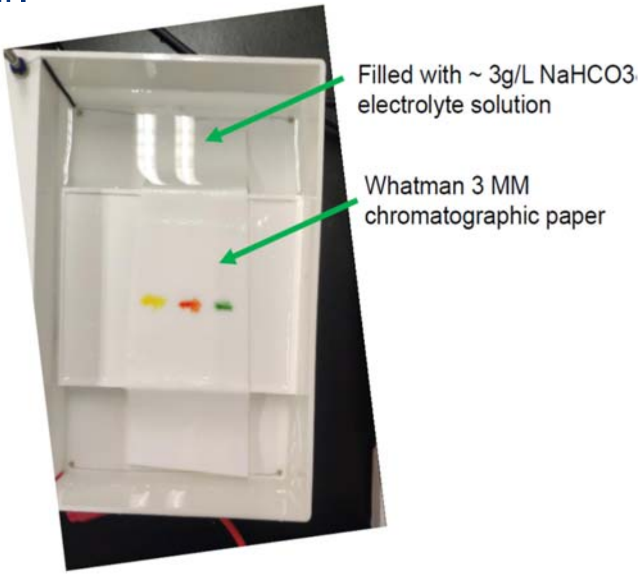
(c) Micropipette

Lab 3: Test Procedures

- Prepare pigments solutions (~50g/L)

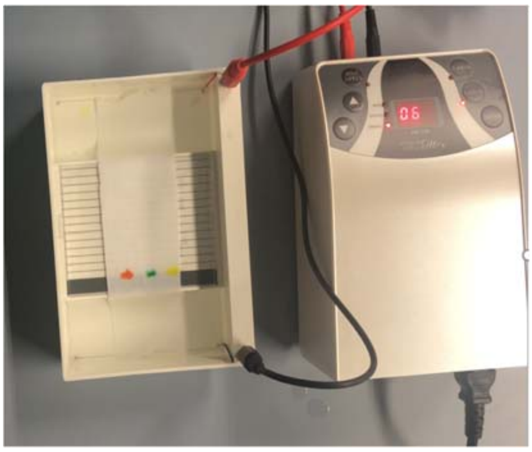
Lab 3: Test Procedures

- Fill the reservoir with ~3g/L $NaHCO_3$ electrolyte solution.
- Attach a Whatman 3 MM chromatographic paper (4 cm width) on the reservoir.



Lab 3: Test Procedures

- Drop 2 μL solutions for each color onto the chromatographic paper using a pipette.
- Set the voltage from the power supply as 90V, 180V, and 300V in a sequence. Each voltage lasts for 5 minutes.



Lab 3: Test Procedures

- Observe and capture the electrophoresis results at a 1 min interval.

Lab 3: Test

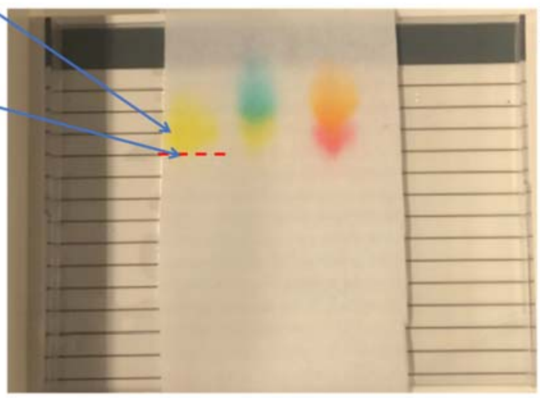
- Watch the video: EP_Video.MP4
- Read the Operation manual.pdf
- Results are in the files:
  - 90V results.pptx
  - 180V results.pptx
  - 300V results.pptx

Lab 3: Test

Electrophoresis system

Lab 3: Report and Discussions

- Describe the principle and methods of electrophoresis.
- Plot the displacement vs time curves of the food dyes with different colors (e.g. the yellow color in the left) at different voltages. Plot one curve for each voltage applied.

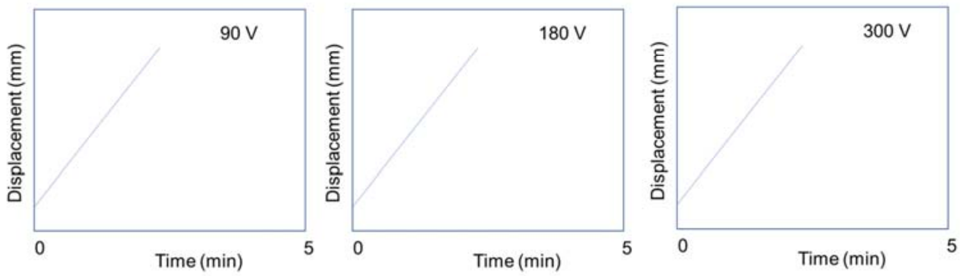


Distance between two parallel lines is 5 mm.

Lab 3: Report and Discussions

Sample result format

1. Plot one curve for each voltage condition.



- Analyze the results. Find the speeds for each case and discuss how the speeds are related to the setup.
- Discuss how to efficiently separate the food dyes using electrophoresis, the potential applications, and so on.