NEXA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF APPLIED SCIENCES & ENGINEERING

ANNUAL LABORATORY PRACTICAL EXAMINATION

PHYS-301: ADVANCED INSTRUMENTATION & PHYSICS LAB

Course Coordinator: Dr. Elena Rostova

Academic Session: 2026–2027

CANDIDATE AND STATION DETAILS

Candidate Name:	____________	**Student ID:**	____________
Desk/Station No:	____________	**Date of Exam:**	____________
Invigilator Name:	____________	**Sign-off:**	____________

CANDIDATE INSTRUCTIONS & ROTATION RULES

1. This practical exam consists of **three stations** (Station 1, Station 2, and Station 3).
2. You will have exactly **50 minutes** at each station. When the timer rings, you must stop writing immediately and rotate to the next station as directed by the invigilator.
3. Make sure you wear a standard laboratory coat and safety goggles. Laser goggles must be worn during Station 2.
4. Answer all tasks within the designated areas and grids provided in this booklet.
5. All measurements and calculations must include appropriate SI units and error analysis where requested.
6. Scientific, non-programmable calculators are allowed. No mobile phones or smartwatches are permitted.

MARK ALLOCATION SUMMARY (FOR EXAMINER USE ONLY)

Station Reference & Core Topic	Max Marks	Marks Obtained	Examiner Initials
Station 1: Electronics & Signal Conditioning	15		
Station 2: Optics & Interferometry	15		
Station 3: Thermodynamics & Calibration	10		
TOTAL EXAM SCORE	**40**		

1 Station 1: Electronics & Signal Conditioning

APPARATUS AT THIS STATION:
Breadboard, LM741 Operational Amplifier, Dual DC Power Supply ($\pm 12\,\text{V}$), Function Generator, Dual-Channel Digital Storage Oscilloscope (DSO), Resistor $R_1 = 1\,\text{k}\Omega$, Resistor $R_f = 10\,\text{k}\Omega$, Jumper wires, BNC-to-Alligator cables.

1.1 Task Description

In this station, you are required to assemble a **non-inverting amplifier** using the LM741 operational amplifier. You will measure its low-frequency gain and determine the closed-loop -3 dB bandwidth. Make sure to ground all instrument shields to the power supply common terminal.

1.2 Experimental Procedures & Measurements

- ☐ Ensure the main power supply and the signal generator are switched OFF. Identify the pins of the LM741 operational amplifier (Pin 2: Inverting Input, Pin 3: Non-Inverting Input, Pin 6: Output, Pin 7: $+V_{cc}$, Pin 4: $-V_{ee}$). [1]
- ☐ Connect the dual power supply rails to the op-amp: Pin 7 to $+12\,\text{V}$ and Pin 4 to $-12\,\text{V}$. Connect the common ground of the supply to the breadboard ground rail. [2]
- ☐ Wire a non-inverting amplifier configuration. Place $R_1 = 1\,\text{k}\Omega$ between Pin 2 and ground, and $R_f = 10\,\text{k}\Omega$ between Pin 2 and Pin 6 (feedback path). Connect the input signal to Pin 3. [3]
- ☐ Turn on the function generator. Configure it to output a sine wave of $V_{\text{in}} = 100\,\text{mV}$ peak-to-peak (V_{p-p}) at a frequency of $1\,\text{kHz}$. Measure V_{in} and V_{out} on Channels 1 and 2 of the DSO respectively. Record the waveforms and their amplitude. [3]
- ☐ Sweep the frequency from $100\,\text{Hz}$ to $1\,\text{MHz}$ as detailed in Table 1. Record the output voltage amplitude V_{out} at each step. Adjust the timebase on the DSO at high frequencies to resolve the output wave properly. [6]

1.3 Answer Space & Calculations

Frequency	Input V_{in} (V_{p-p})	Output V_{out} (V_{p-p})	Gain $A_v = \frac{V_{\text{out}}}{V_{\text{in}}}$	Gain in Decibels (dB)
$100\,\text{Hz}$	$100\,\text{mV}$			
$1\,\text{kHz}$	$100\,\text{mV}$			
$10\,\text{kHz}$	$100\,\text{mV}$			
$50\,\text{kHz}$	$100\,\text{mV}$			
$100\,\text{kHz}$	$100\,\text{mV}$			
$500\,\text{kHz}$	$100\,\text{mV}$			
$1\,\text{MHz}$	$100\,\text{mV}$			

Table 1: Frequency Response of the Non-Inverting Op-Amp

1. Calculate the theoretical closed-loop voltage gain $A_{v,\text{ideal}}$ of your circuit based on the resistor values:

2. Identify the frequency at which the output voltage drops to 70.7% of its low-frequency value (the -3 dB point). Estimate the experimental bandwidth (BW):

3. Short Question: Slew rate limiting affects high-frequency signals. If you increase the input amplitude to $V_{\text{in}} = 2\,\text{V}$ at $100\,\text{kHz}$, explain what changes you expect to observe in the output waveform, and why.

2 Station 2: Optics & Interferometry

APPARATUS AT THIS STATION:
Helium-Neon Laser ($\lambda \approx 632.8\,\text{nm}$, Class 2), Michelson Interferometer Base, Movable Mirror with Micrometer Drive (L_m), Beam Splitter, Fixed Mirror with alignment screws, Viewing Screen, Laser safety goggles.

2.1 Task Description

In this station, you must align the Michelson interferometer setup to observe concentric circular interference fringes. By moving the micrometer screw, you will count the number of fringe transits and calculate the wavelength of the Helium-Neon laser.

2.2 Experimental Procedures & Measurements

- ☐ **Safety Warning:** Do not look directly into the laser beam or its specular reflections. Put on safety goggles before turning the laser on. **[1]**
- ☐ Align the laser beam so it strikes the center of the beam splitter. Verify that two separate spots of light are projected onto the viewing screen (corresponding to paths from Mirror 1 and Mirror 2). **[2]**
- ☐ Carefully adjust the vertical and horizontal alignment screws on the fixed mirror until the two light spots perfectly overlap on the screen. Adjust the micrometer drive slowly until circular fringe patterns appear. **[4]**
- ☐ Record the initial micrometer reading d_0. Turn the micrometer screw slowly and count the number of fringes passing a marked point on the screen. For every $N = 50$ transits, record the micrometer position d_i. Run 4 trials (up to $N = 200$). **[5]**
- ☐ Calculate the mirror displacement $\Delta d = d_i - d_0$ for each trial, and compute the experimental laser wavelength λ using $2\Delta d = N\lambda$. Note down the micrometer scale calibration factor (if any). **[3]**

2.3 Answer Space & Calculations

Trial	Fringes (N)	Micrometer Reading d (mm)	Displacement Δd (mm)	Wavelength λ (nm)
Start	$N = 0$		—	—
1	$N = 50$			
2	$N = 100$			
3	$N = 150$			
4	$N = 200$			

Table 2: Michelson Interferometer Fringe Measurement Data

1. Calculate the mean value of the experimental laser wavelength ($\bar{\lambda}$) and its absolute error. Show your steps:

2. Compare your experimental wavelength with the standard value of $632.8\,\mathrm{nm}$. Determine the percentage error of your measurement:

3. Short Question: If the light source is changed to a broadband white-light source, describe what you would observe on the viewing screen, and explain why circular fringes are difficult to maintain.

3 Station 3: Thermodynamics & Sensor Calibration

APPARATUS AT THIS STATION:
Platinum Resistance Thermometer (Pt100 RTD sensor), Reference Glass-in-Mercury Thermometer, Ice-Water Bath, Boiling Water Bath (Heater), Digital Multimeter (DMM) with 4-wire resistance Kelvin clips, connection cables, thermal paste.

3.1 Task Description

In this station, you are required to calibrate a Pt100 RTD sensor at the ice point ($0.0\,°\mathrm{C}$) and steam point ($100.0\,°\mathrm{C}$). You will determine the sensor's temperature coefficient of resistance (α) and use it to measure the ambient room temperature.

3.2 Experimental Procedures & Measurements

☐ Connect the four leads of the Pt100 sensor to the DMM using a 4-wire configuration (two force leads, two sense leads). Switch the DMM to the resistance measurement mode (Ω) on the lowest manual range that covers $200\,\Omega$. **[2]**

☐ Place the Pt100 probe alongside the reference glass thermometer in the ice-water bath. Wait at least 3 minutes for thermal equilibrium. Record the temperature from the glass thermometer T_{ice} and the corresponding resistance R_{ice}. **[2]**

☐ Carefully transfer the Pt100 probe to the boiling water bath. Allow the temperature reading to stabilize. Record the reference thermometer temperature T_{steam} and the corresponding resistance R_{steam}. **[2]**

☐ Use your recorded values to calculate the temperature coefficient of resistance α of the Pt100 sensor. Recall: $R(T) = R_0(1 + \alpha T)$, where $R_0 = 100.0\,\Omega$ at $T = 0.0\,°\mathrm{C}$. **[2]**

☐ Remove the probe from the boiling bath, dry it, and let it cool. Record the resistance of the sensor at room temperature R_{room}. Use your calculated α to estimate the room temperature T_{room}. **[2]**

3.3 Answer Space & Calculations

Measurement Point	Reference Temp. T ($^{\circ}$C)	Measured Resistance R (Ω)
Ice-Water Bath (Ice Point)		
Boiling Water Bath (Steam Point)		
Ambient Room Air (Uncalibrated)	—	

Table 3: Resistance-Temperature Calibration Data

1. Calculate the temperature coefficient of resistance (α) of your Pt100 probe. Show all equations and calculation steps:

2. Calculate the room temperature T_{room} based on your experimental resistance R_{room} and α:

3. Short Question: Why is a 4-wire resistance measurement preferred over a 2-wire measurement for low-resistance RTD calibration? Detail the path of current and voltage sensing.

4 Configilator Guide & Rubric (Confidential)

CONFIDENTIAL — FOR LAB STAFF & INVIGILATORS ONLY

This section contains sensitive setup details, expected measurement values, and grading rubrics. It must be detached or kept confidential from candidates during the exam period.

4.1 Laboratory Setup & Calibration Requirements

To ensure the integrity and safety of the exam, the lab technician must verify the following settings at least **2 hours** before the exam begins:

4.1.1 Station 1 (Electronics)

- Power rails must be set exactly to $\pm 12.0\,\mathrm{V}$ with current limits set to $100\,\mathrm{mA}$ to prevent thermal damage in case of incorrect wiring.
- Function generator output should be set to high impedance ($Z_{\text{in}} = \text{High-Z}$) with amplitude calibration checked.
- Keep a tray of spare LM741 operational amplifiers and resistor sets at the supervisor's desk.

4.1.2 Station 2 (Optics)

- Secure the He-Ne lasers on optical rails to prevent accidental misalignment.
- Pre-align the mirrors roughly to ensure students do not spend more than 5 minutes searching for the first fringe patterns.
- Post Laser Hazard Warning signs outside the laboratory entry doors.

4.1.3 Station 3 (Thermodynamics)

- Provide freshly crushed ice from the laboratory ice machine to maintain the ice bath at exactly $0.0\,^{\circ}\mathrm{C}$.
- Verify that the heating elements in the boiling baths are functioning safely and that water levels are topped up.
- Check that the digital multimeters are set to 4-wire resistance measurement mode and the leads are calibrated for zero resistance.

4.2 Expected Measurements & Grading Rubric

Task Item	Max Marks	Grading Criteria & Expected Performance
Station 1 Circuit Assembly	3 marks	Correct pin connections for power supply and feedback resistors. Zero shorts.
Station 1 DSO Operation	3 marks	Clear input and output waveforms displayed with correct amplitude readouts.
Station 1 Freq Response Table	6 marks	Complete data points; correct calculation of decibels $20\log_{10}(A_v)$.
Station 1 Slew Rate Answer	3 marks	Mentions signal distortion, triangular wave output, and slew rate limit ($0.5\,\mathrm{V\,\mu s^{-1}}$).
Station 2 Laser Alignment	6 marks	Aligning mirrors safely; getting circular concentric fringe patterns on screen.
Station 2 Fringe Counting	5 marks	Proper micrometer recording; displacement matches the counted fringe count.
Station 2 Calculation & Error	4 marks	Correct formula $2\Delta d = N\lambda$; error within $\pm 20\,\mathrm{nm}$ of standard $632.8\,\mathrm{nm}$.
Station 3 4-Wire Wiring	4 marks	Correct terminal configurations on DMM. Proper lead attachment.
Station 3 Temp Coeff (α)	4 marks	Correct calculation: $\alpha \approx 3.85 \times 10^{-3}\,\mathrm{^{\circ}C^{-1}}$ for standard Pt100.
Station 3 Room Temp Measure	2 marks	Reasonable room temp measurement ($18\,^{\circ}\mathrm{C}$ – $26\,^{\circ}\mathrm{C}$ depending on HVAC).

Table 4: Examiner Detailed Grading Standards

References

[1] Sarah Smith and Julian Vance. *Introduction to Practical Electronics and Instrumentation*. Nexa Academic Press, 3rd edition, 2024.

[2] Meridian Safety Board. Laboratory safety standards and laser hazards guide. Technical Report MIT-LS-2025-04, Meridian Institute of Technology, 2025.

[3] Elena Roster and Arthur Pendelton. Calibration and error analysis in platinum resistance thermometry. *Journal of Applied Physics Education*, 45(2):112–120, 2023.