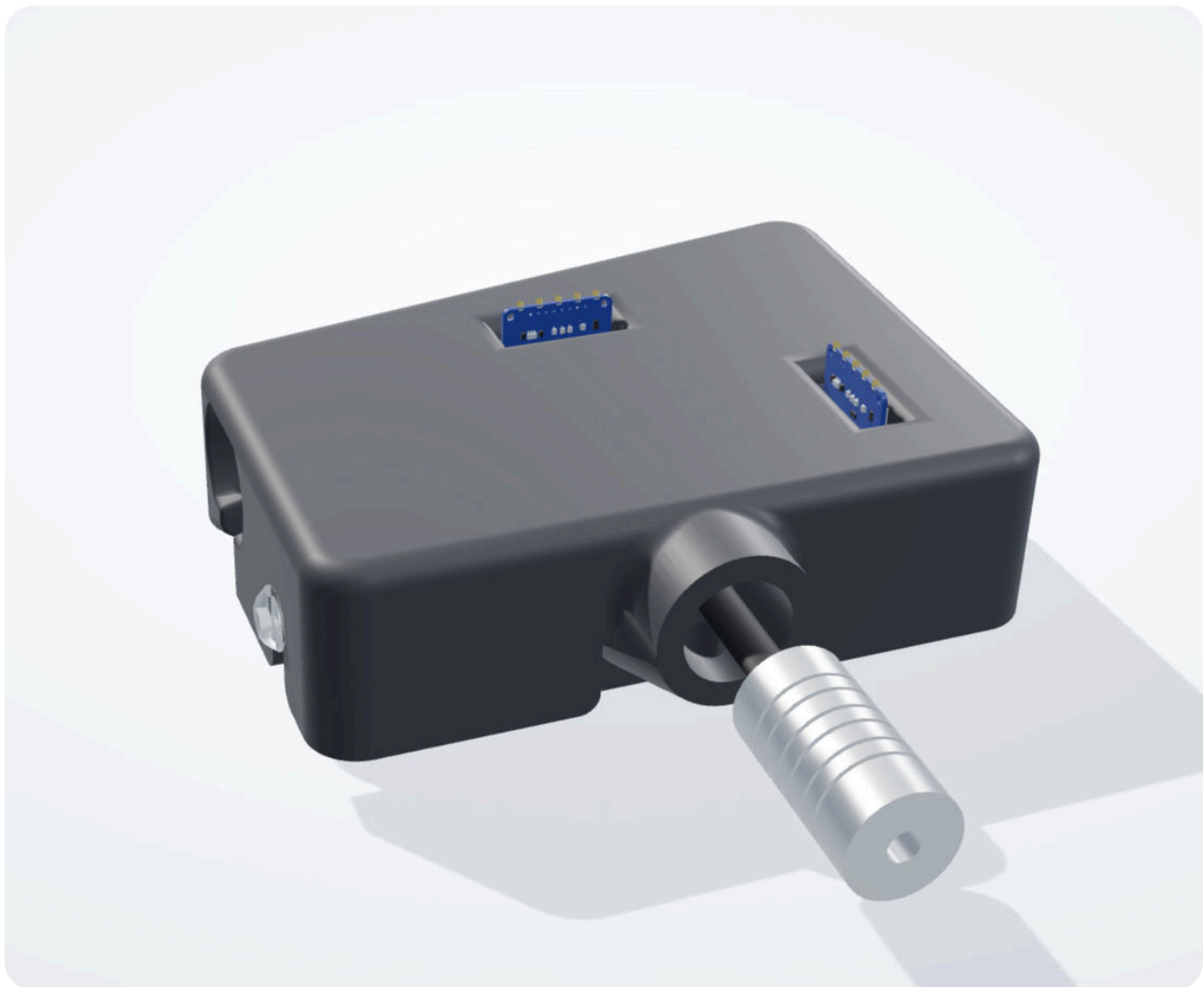


Slim Photometer

Assembly guide

A low-cost in-line OD600 meter for the bioreactor. Two optical fibers carry 600 nm light from one illuminator: one across the culture in a 2 mm flow cuvette to the sample sensor, one across an empty chamber to the reference sensor.



Before you start

SAFETY

- ◆ The soldering iron runs at 350 °C. Keep it in its stand and never touch the tip.
- ◆ Solder in a ventilated room or under a fume extractor. Do not breathe the smoke.
- ◆ Wear eye protection when you solder or cut wire.
- ◆ Unplug the Arduino before you change any wiring.
- ◆ Let the heat gun cool on a heat-safe surface.
- ◆ Heat-set inserts stay hot after you press them in. Let them cool before you touch them.
- ◆ The flow cuvette is glass. Handle it gently.

Tools and supplies

- 3D printer (Bambu Lab X1 Carbon), Bambu Studio
- Soldering iron, wet sponge
- Heat gun
- Side cutters, wire stripper and pliers
- Allen keys for the M3 and M4 screws
- Multimeter with a continuity (beep) setting
- Computer with Arduino App Lab
- Clean culture medium, for the blank
- Eye protection

Parts checklist from the wiki's materials list (Photometer page, 11.1), with the screws and the inserts

QTY	PART	DETAILS
LIGHT PATH		
☐	1 Fiber optic light	600 nm, PMMA: the fiber illuminator and its two optical fibers
☐	1 Flow cuvette	2 mm inner, 4 mm outer diameter, 76 mm long
☐	2 Lux sensors	GY-302 (BH1750FVI): one sample, one reference
ELECTRONICS		
☐	1 Arduino Uno Q	
☐	1 PCB	2 × 8 cm prototype board
☐	1 Transistor	UTC PN2222
☐	3 Resistors	330 Ω, 1.2 kΩ and 10 kΩ, one of each
☐	12 Wires, 20 AWG	330 mm (12 + 1 in): 3 black, 3 red, 2 green, 2 blue. 610 mm (24 in): 1 red, 1 black
☐	2 Heat-shrink tubes	2.0 × 45 mm
☐	30 2510 connectors	Female: 2 × 5-pin, 4 × 2-pin. Male: 2 × 5-pin, 4 × 2-pin. 18 crimp pins
☐	20 DuPont connections	10 female crimp pins, 2 × 5-pin female housings
☐	10 Male header pins, bent	in one strip of 10
BODY		
☐	Filament	124.11 g black PLA and 24.78 g black TPU 95A
☐	8 Screws	6 × M3 × 8 mm for the clips, 2 × M4 × 12 mm for the case
☐	6 Heat-set inserts, M3	brass, M3 × 5.7 mm long, 4.6 mm outer diameter, for a 4.0 mm hole
☐	1 Roll of solder	lead-free

Files

Print files

Download the STL files from the Design Files section of our wiki's Photometer page.

Inline Photometer app

v1.2.0, for Arduino App Lab on the Uno Q. Download it from the Code section of our wiki's Photometer page.

STAGE 1 Print the parts

YOU NEED

- 3D printer with black PLA and black TPU 95A
- The 3 STL files

Printer	Bambu Lab X1 Carbon, 0.4 mm nozzle, textured PEI plate	Profile	0.20 mm Standard @BBL X1C, changed to a 0.16 mm layer height; first layer 0.2 mm
Top surface	Line width 0.25 mm	Infill	100 %, rectilinear
Supports	On: tree (auto), 30° threshold, not on build plate only; remove small overhangs on; no raft	Filament	Black PLA for every part. TPU 95A painted on the seats and pads of the body
Copies	Body and case: 1 each. Clip: 3		

- 1 Download the 3 STL files from the Design Files section of our wiki's Photometer page.
- 2 Open them in Bambu Studio, with the settings in the table.
- 3 Add the clip three times.
The same part is the front clip, the sample clip and the reference clip.
- 4 Set every part's filament to black PLA.
- 5 Paint TPU 95A onto the seats and pads of the body 1.
They are where the flow cuvette and the two sensors sit; the TPU grips them.
- 6 Slice each plate and print it.
- 7 Remove the supports.



1 Body



2 Case



3-5 Clips, ×3

CHECK

1. You have all 5 printed parts: the body, the case and three clips. The body has TPU on its seats and pads.

YOU NEED

- The fiber illuminator; the red and black 610 mm (24 in) wires; 2 heat-shrink tubes; a 2-pin 2510 female connector and 2 crimp pins
- Side cutters, wire stripper, pliers, soldering iron, heat gun, multimeter

- 1 Cut the USB-A plug off the illuminator's cable, close to the plug.
- 2 Strip 30 mm (1.2 in) of the cable's outer jacket, then 10 mm (0.4 in) off the red and black wires inside. If there are also white and green wires, cut them short: they are not used.
- 3 Identify + and -: by the USB colour code, red is +5 V and black is GND.
Confirm with the multimeter on its diode setting: the illuminator glows faintly when the red probe touches + and the black probe touches -.
- 4 Twist the red and black 610 mm wires together.
Leave about 75 mm (3 in) untwisted at each end.
- 5 At one end, strip 10 mm (0.4 in) off each wire.
- 6 Slide a heat-shrink tube onto each 610 mm wire, well back from the bare end.
- 7 Twist the bare red wire onto the illuminator's red (+) wire, and the bare black wire onto its black (-) wire.
- 8 Heat the soldering iron to 350 °C.
- 9 Solder each joint: hold the iron on the joint to heat it, then feed solder into the joint until it flows round both wires.
Feed the solder to the joint, not to the iron. Take the solder away first, then the iron. Let the joints cool for 30 seconds.
- 10 Slide each heat-shrink tube over its bare joint, shrink it with the heat gun, then twist the wires tight again.
- 11 At the other end, strip 8 mm (0.3 in) off each wire.
- 12 Lay the red wire in a 2510 crimp pin: large tabs on the insulation, small tabs on the bare wire.
- 13 With pliers, fold the large tabs to grip the insulation, then the small tabs onto the bare wire.
- 14 Solder the small tabs to the wire.
Keep solder off the large tabs, or the pin will not seat.
- 15 Crimp the black wire the same way (steps 12 to 14).
- 16 Push the red pin into the left slot of a 2-pin 2510 female connector until it clicks. Push the black pin into the right slot.
Tug each wire: it must not pull out.

CHECK

1. Push the illuminator connector onto a 2-pin 2510 male connector. It must seat fully.

If it fails: Solder ran onto the large tabs of a crimp pin and blocks it. Redo that pin.

YOU NEED

- 10 wires, 330 mm (12 + 1 in): 3 black, 3 red, 2 green, 2 blue
- 10 DuPont female crimp pins and 2 × 5-pin female housings
- 10 × 2510 crimp pins and 2 × 5-pin 2510 female connectors
- For the checks: the strip of 10 bent header pins and 2 × 5-pin 2510 male connectors
- Wire stripper, pliers, soldering iron

- 1 Cut 25 mm (1 in) off each of the 10 wires.
Keep the 10 short pieces: they are the PCB's jumpers (Stage 4).
- 2 Strip 8 mm (0.3 in) off both ends of the 10 long wires.
- 3 Crimp a DuPont female pin onto one end of each wire, as in Stage 2.
Large tabs on the insulation, small tabs on the wire, then solder the small tabs.
- 4 Push the pins into the two DuPont housings until they click, in the order below.

	ADDR	SDA	SCL	GND	VCC (3.3 V)
Housing 1 · sample ADDR to 3.3 V · I ² C 0x5C	red	blue	green	black	red
Housing 2 · reference ADDR to GND · I ² C 0x23	black	blue	green	black	red

Read each housing from its ADDR end. This is the GY-302's own pin order, VCC, GND, SCL, SDA, ADDR, reversed: check it against the labels printed on your board before you plug a housing in. The red VCC wires go to the Uno Q's 3.3 V; SDA goes to D20 and SCL to D21.

✓ CHECK · TEST 1

1. Push each DuPont housing onto the bent header pins. It must fit.
2. Pull the header pins out again.

If it fails: Solder on a crimp pin ran too close to the insulation and blocks the header pin. Redo the pins of that housing.

- 5 Crimp a 2510 pin onto the other end of each wire, the same way.
- 6 Push the pins into the two 5-pin 2510 female connectors until they click.
Keep each cable's wires in the same order as its DuPont housing. Never mix the two cables in one connector.
- 7 Label the cables: sample (housing 1) and reference (housing 2).

✓ CHECK · TEST 2

1. Push each 2510 female connector into a 5-pin 2510 male connector. They must click together.
2. Take the male connector off again.

If it fails: Solder on a crimp pin ran too close to the insulation and blocks the connector. Redo that connector's pins.

STAGE 4

Solder the sensors and the PCB

YOU NEED

- Both GY-302 sensors
- The strip of 10 bent header pins
- The 2 × 8 cm PCB
- The six 2510 male connectors
- Resistors: 330 Ω, 1.2 kΩ and 10 kΩ
- The PN2222 transistor
- The 10 short wires from Stage 3
- Soldering iron, solder, wire stripper, multimeter

THE SENSORS

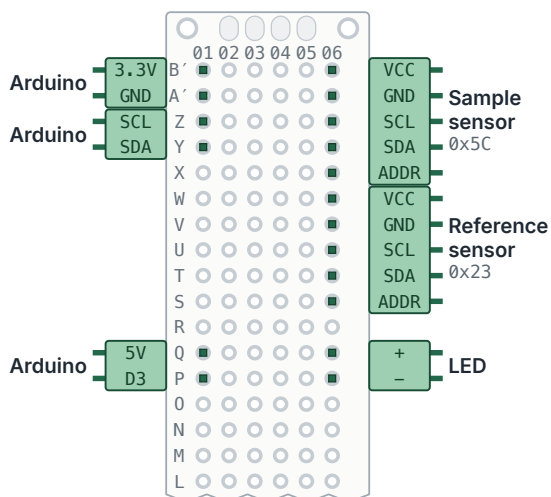
- 1 Snap the header strip into two strips of 5 pins.
- 2 Put one strip into the five holes of a GY-302.
- 3 Solder each pin to its pad: heat the pin and the pad together, then feed solder into the joint.
Keep the iron on the board briefly: too long melts the plastic and spoils the joint.
- 4 Check that no solder joins two pins.
- 5 Solder the second sensor the same way.

✓ CHECK · THE SENSORS

1. On both sensors, every pin is soldered and no solder joins two pins.

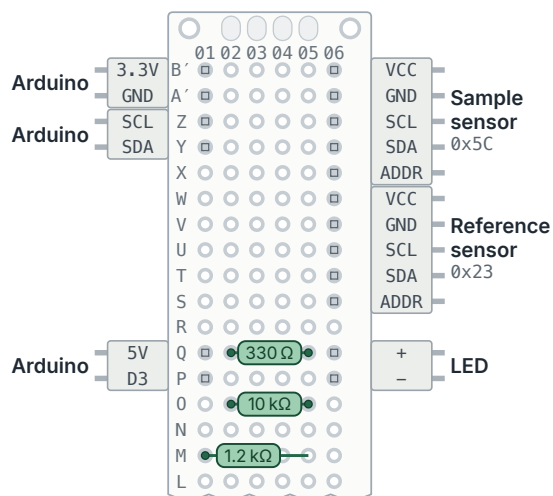
THE PCB

The PCB is the hardest soldering in this guide and needs basic soldering experience. If you have never soldered, practise on a spare piece of perfboard first, or do this part with someone who has. Hold the PCB as in the pictures, columns 01 to 06 from left to right. Its rows are lettered up from the bottom edge, A to Z, then A and B again: this guide calls those top two **A'** and **B'**. A hole is named by row, then column: Q02 is row Q, column 02. Parts go in from the component side and are soldered on the solder side, underneath. Green in each picture is what the step adds.

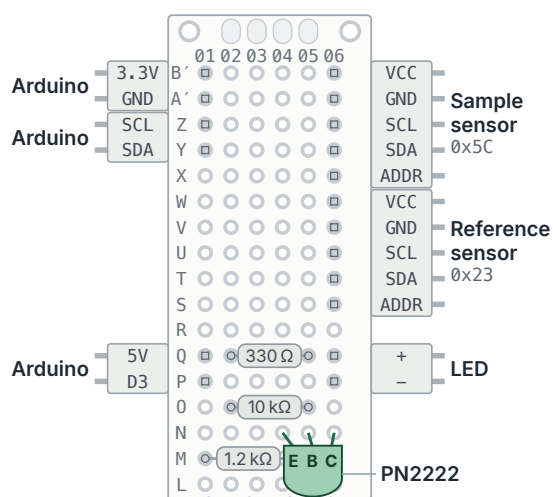


Component side. Green: the six connectors.

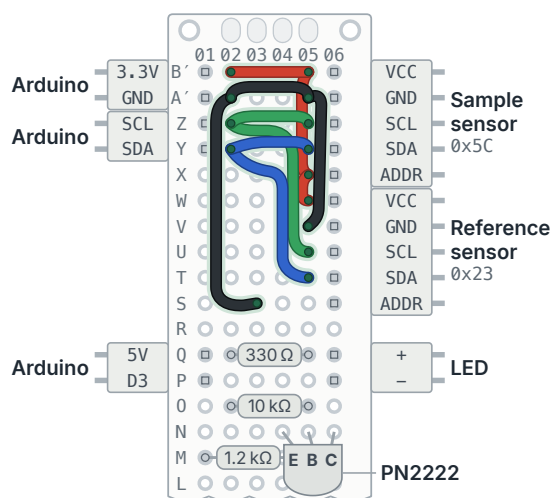
- 6 Push the six 2510 male connectors into the PCB from the component side, their pins pointing out past the edge.
Left edge, column 01: three 2-pin connectors for the Arduino, in rows B'–A', Z–Y and Q–P. Right edge, column 06: the sample sensor's 5-pin connector in rows B' to X, the reference sensor's in rows W to S, and the LED's 2-pin connector in rows Q–P.
- 7 Turn the board over. Solder one pin of each connector, check that the connector sits flat, then solder its other pins.
18 pins in all.



Component side. Green: the three resistors.



Component side. Green: the transistor.



Component side. The ten jumpers, in their colours.

- 8** Bend each resistor's leads down and push them through from the component side, into the holes below.

The 1.2 kΩ sits to the left; its right lead runs on to M05.

RESISTOR	BANDS	HOLES
330 Ω	orange, orange, brown, gold	Q02, Q05
10 kΩ	brown, black, orange, gold	O02, O05
1.2 kΩ	brown, red, red, gold	M01, M05

- 9** Solder each lead on the solder side, then trim it.

- 10** Find the emitter (E), base (B) and collector (C) of your PN2222 in its datasheet.

Check before you solder: the pin order differs between makes, E-B-C on some and C-B-E on others.

- 11** Push E into N04, B into N05 and C into N06, from the component side. Fold the body down flat over rows M and L.

E goes to ground, B to the two resistors, C to the LED's – pin.

- 12** Solder the three legs and trim them.

- 13** Cut the 10 short wires from Stage 3 to fit the routes in the picture. Strip 3 mm (0.1 in) off each end.

- 14** Push both ends of each wire through from the component side, as in the table, and solder them. Six holes take two wire ends: B'05, X05, A'02, A'05, Z02 and Y02. Put both ends in before you solder; if the second will not fit, solder it onto the first one's joint on the component side.

COLOUR	CARRIES	EACH WIRE, FROM → TO
red	3.3 V	B'02 → B'05, B'05 → X05, X05 → W05
black	GND	A'02 → A'05, A'05 → V05, A'02 → S03
green	SCL	Z02 → Z05, Z02 → U05
blue	SDA	Y02 → Y05, Y02 → T05



- 17** Make the six traces: run solder from hole to hole along each green line.
On the long ones, a trimmed lead laid along the holes and soldered at each makes it easier.

18 Check that no solder joins two lines the picture keeps apart.
Look hardest where they run side by side: columns 04 to 06 in rows Q to N, and rows S and T.

1. **GND:** the left GND pin beeps to both sensors' GND pins and to the reference sensor's ADDR pin.
2. **3.3 V:** the left 3.3 V pin beeps to both sensors' VCC pins and to the sample sensor's ADDR pin.
3. **SDA, SCL:** each beeps from the left edge to the same pin on both sensor connectors.
4. **No shorts:** no beep between any two of GND, 3.3 V, 5 V, SDA and SCL; between 5 V and D3; or between the LED's + pin and GND or its – pin.
5. **330 Ω :** on the Ω setting, the left 5 V pin reads about 330 Ω to the LED's + pin.

8 / 13

YOU NEED

- Both sensors, with their header pins
- The two sensor cables and the illuminator cable
- The PCB and the Arduino Uno Q
- A computer with Arduino App Lab
- The Inline Photometer app, v1.2.0

- Push housing 1 onto the sample sensor's pins and housing 2 onto the reference sensor's pins.
- Plug the cables into the PCB's 2510 male connectors on its right edge: the sample cable (housing 1) into the top 5-pin connector, the reference cable (housing 2) into the one below it, and the illuminator cable into the 2-pin LED connector.
The PCB sets each sensor's address (ADDR to 3.3 V on the top connector, 0x5C; to GND on the other, 0x23), so each cable must go to its own connector. Each sensor cable reads red, black, green, blue from the top pin down; the illuminator cable's red wire is on the top pin.
- Connect the three 2-pin connectors on the PCB's left edge to the Arduino Uno Q, as in the table below.

PCB PIN	UNO Q PIN	CARRIES
3.3 V	3.3 V	the sensors' supply (the red wires)
GND	GND	ground
SCL	D21	the I ² C clock (the green wires)
SDA	D20	the I ² C data (the blue wires)
5 V	5 V	the illuminator's supply
D3	D3	the illuminator switch: to the transistor's base, through 1.2 kΩ

- In Arduino App Lab, make a new app. Copy in **app.yaml**, the **sketch** and **python** folders, and **assets/index.html**.
The python folder must include `photometer_algos.py`.
- Add the brick **WebUI – HTML**.
- Add the sketch library **Arduino_RouterBridge**.
- Click **Run** and read the [boot] lines in the console.

```
[boot] step 2/4: I2C probe 0x5C / 0x23
[boot] sample 0x5C: ok (0 ms)
[boot] reference 0x23: ok (0 ms)
```

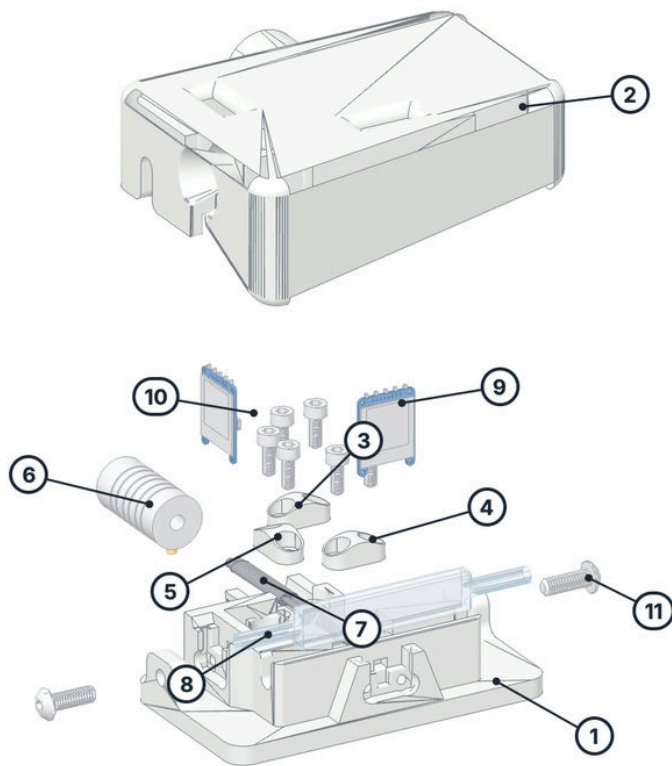
✓ CHECK · TEST 3

- The console shows **sample 0x5C: ok** and **reference 0x23: ok**.
- In a bright room, cover each sensor with a finger in turn.
- Its reading drops from a high value to near zero.

If it fails: **nak** means no device at that address: no power, or ADDR wired wrong (check the housing order). **timeout** means a bus problem: SDA or SCL shorted or pulled low, or GND missing. A failed sensor is retried every 10 seconds, so it comes back once the wiring is fixed.

YOU NEED

- The 5 printed parts
- The illuminator on its cable, and its two fibers
- The flow cuvette
- Both sensors, on their cables
- 6 × M3 heat-set inserts and the soldering iron to press them in
- Screws: 6 × M3 × 8, 2 × M4 × 12
- Allen keys



The parts, numbered as on the wiki (Photometer page, 7.3). They go together in the reverse order of the exploded view: the inserts and the fibers into the body, the clips over the fibers, the cuvette and the sensors into their seats, then the case.

PRINTED

- ① Body
- ② Case
- ③ Front clip
- ④ Sample clip
- ⑤ Reference clip

BOUGHT

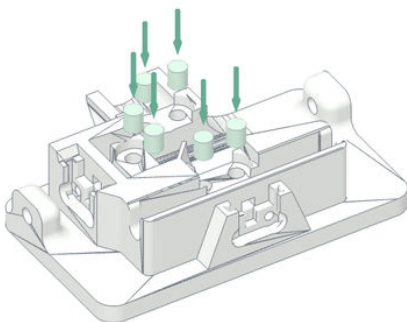
- ⑥ Fiber illuminator
- ⑦ Optical fibers ×2
- ⑧ Flow cuvette
- ⑨ Sample sensor (GY-302)
- ⑩ Reference sensor (GY-302)
- ⑪ Screws: 6 × M3 × 8, 2 × M4 × 12

Green in pictures A to E marks the parts each group of steps adds.

THE INSERTS · A

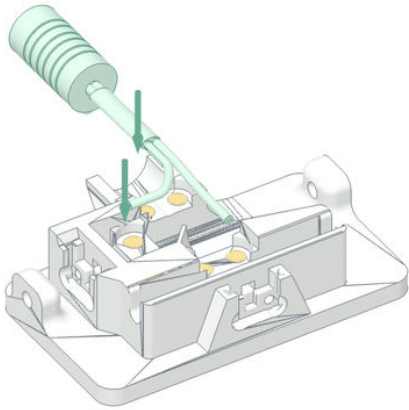
- 1 Press an M3 heat-set insert into each of the six screw holes on the top of the body ①, with the hot soldering iron, until it sits flush.

Two holes each side of the fiber channel at the back, two beside the sample fiber's tip, two beside the reference fiber's tip. Let them cool.



A six M3 inserts into the body.

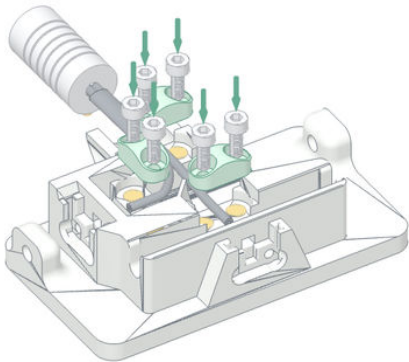
THE FIBERS · B



B the illuminator and its two fibers.

- 2 Push both fibers ⑦ into the front of the illuminator ⑥, as far as they go, and tighten its locking screw.
- 3 Lay the two fibers in the half-sleeve at the back of the body, then on into their channels.
The straight fiber runs on to the sample side; the other turns 90° to the reference side.
- 4 Slide the sample fiber forward until its tip reaches the end of its channel, 1 mm from the cuvette channel.
If a fiber is too long to lie flat, cut it with a sharp blade in one square cut.
- 5 Slide the reference fiber until its tip reaches the end of its channel, at the empty chamber.

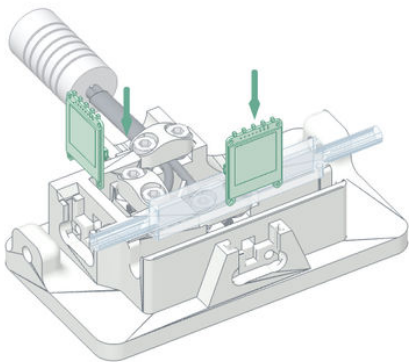
THE CLIPS · C



C the three clips, each with 2 × M3 × 8.

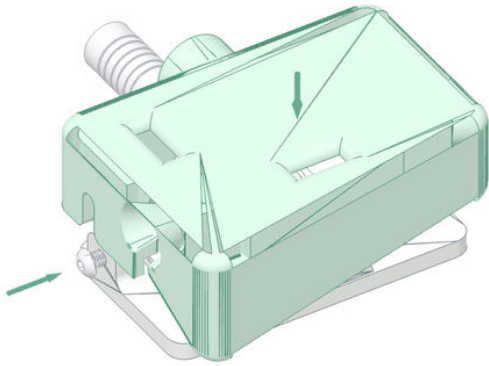
- 6 Lay the front clip ③ across both fibers where they enter the body, and fix it with 2 × M3 × 8 screws.
- 7 Lay the sample clip ④ over the sample fiber's tip and fix it with 2 screws.
- 8 Lay the reference clip ⑤ over the reference fiber's tip and fix it with 2 screws.
- 9 Tighten each pair evenly, until its fiber cannot slide.
Do not overtighten: the fibers are plastic and crush.

THE CUUVETTE AND THE SENSORS · D



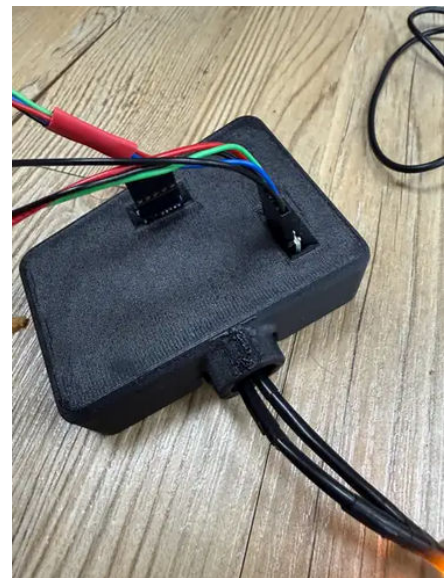
D the flow cuvette and both sensors.

- 10 Lay the flow cuvette ⑧ in its channel across the body, in front of the sample fiber's tip.
It is glass and breaks easily: handle it gently.
- 11 Press the sample sensor ⑨ into its slot beyond the cuvette, its chip facing the cuvette and its pins up.
Check the direction before you press it in: a sensor put in backwards faces away from the light.
- 12 Press the reference sensor ⑩ into its slot at the end of the empty chamber, its chip facing the chamber and its pins up.
The same check: chip toward the chamber, pins up.



- 13 Drive an M4 × 12 screw into the hole in each end of the body, leaving about 4 mm between its head and the body.
Each screw cuts its own thread in the plastic.
- 14 Lower the case 2 over the body. The slots in its end walls slide down over the two screws.
The sensor pins and their cable housings come up through the two windows in its top, the fibers leave through the sleeve at the back, and the cuvette's ends through the round openings at the ends.
- 15 Tighten both M4 screws.

E the case, held by 2 × M4 × 12.



The Slim as built: the fibers clamped under their clips (left); both sensors in place and wired (centre); closed, with the sensor pins through the case (right).

YOU NEED

- The assembled photometer, wired up and running the app
- Clean culture medium

- 1 In the app's light-path setting, choose **Fiber (dual, free ratio)**.
- 2 Turn on alignment mode. The illuminator stays on.
- 3 Check that both readings are high, but not at 100 %.
If one is low or at 100 %, loosen that fiber's clip, reseal its tip square at the end of its channel and tighten the clip again.
- 4 Turn off alignment mode.
- 5 Fill the flow cuvette with clean medium.
- 6 Press **Blank**.
In the bioreactor, blank only after sterilizing and rinsing (bioreactor guide, Stage 6).

CHECK · TEST 4

1. In alignment mode, both readings are high and neither is at 100 %.
2. After the blank, the OD600 of the clean medium reads close to 0.

If it fails: Reseat the fiber tips and blank again. The fiber split is not fixed: blank again whenever a fiber is bumped, reseated or moved.

Reading on the Pro's scale. The Slim reads OD600 at about one fifth of the Pro's scale. Multiply its reading by **5.57** to read on the same scale as the Pro and the BioDrop (Pro $\approx 5.57 \times$ Slim – 0.07; Photometer page, 5.2.3). The factor comes from one silica standard, so on culture it is approximate.