



Biomedical Sensors

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Medical Devices and Human Engineering

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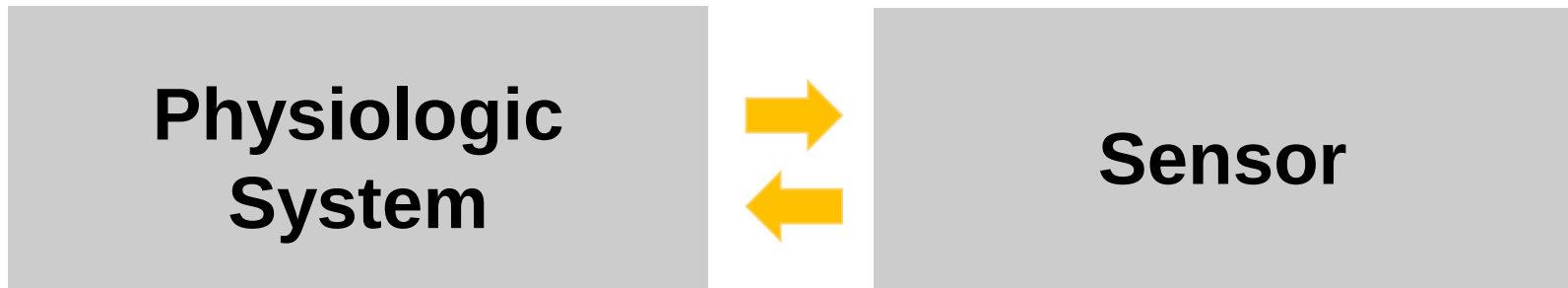
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Block diagram of a general biomedical instrument



Rejection

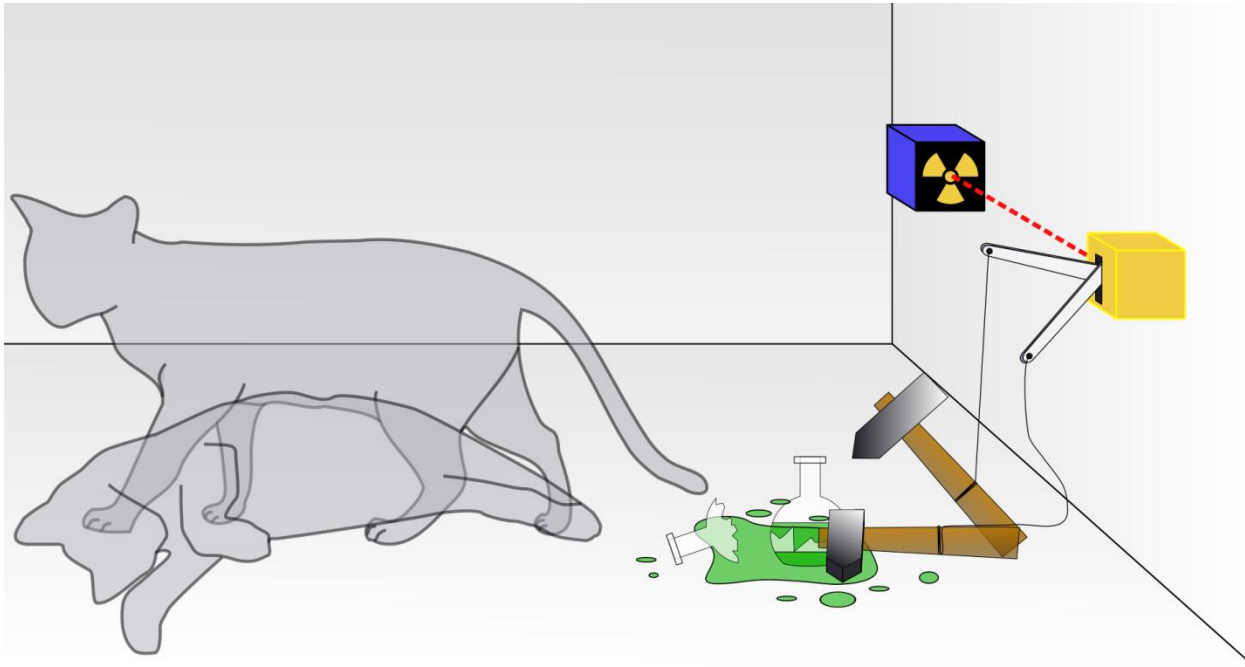


**Physiologic
System**



Sensor

Schrödinger's Cat



**Physiologic
System**



Sensor

Erwin Schrödinger 1935

Classification of Biomedical Sensors

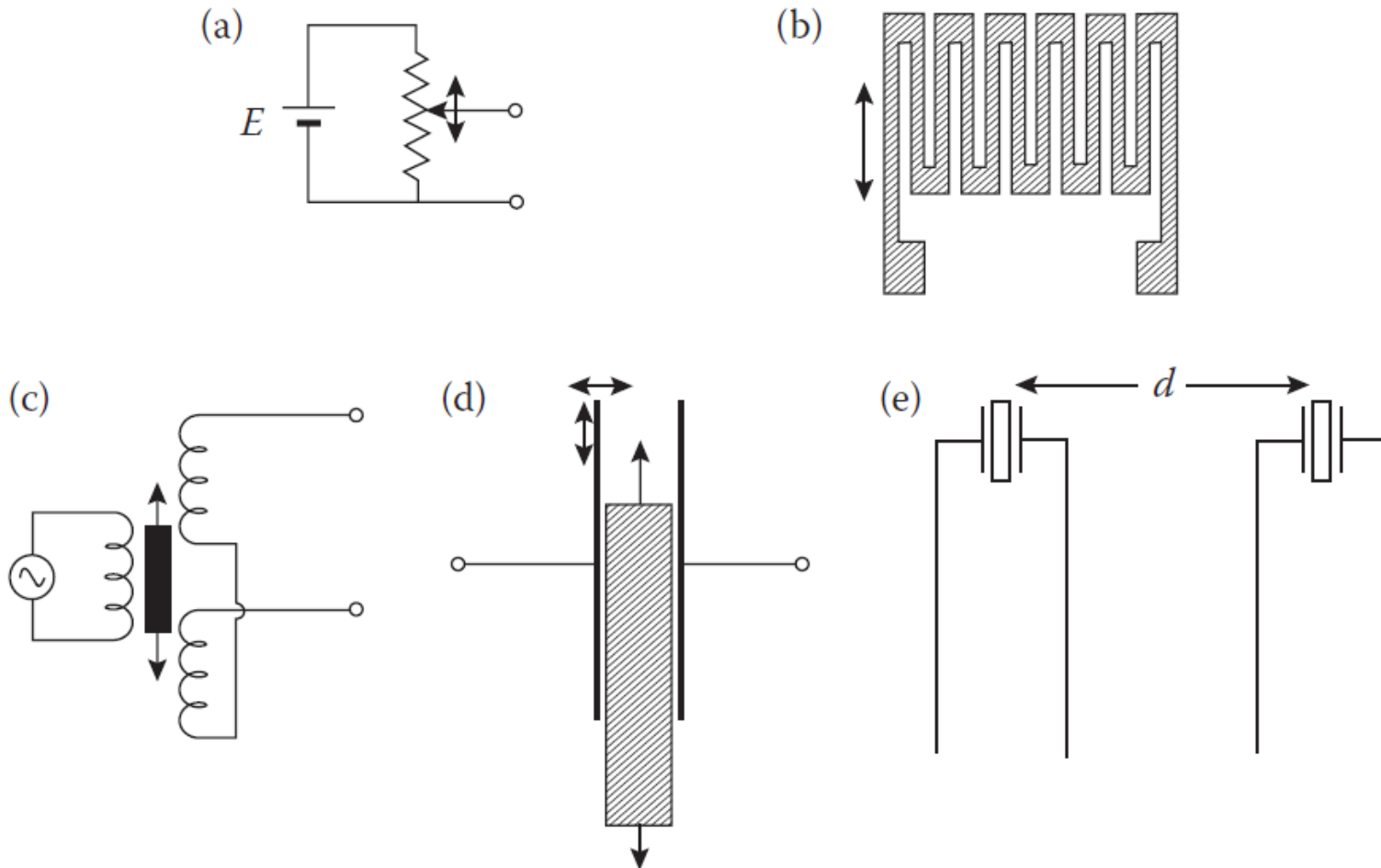
Physical Sensors	Chemical Sensors
• Displacement • Linear • Angular • Volume • Mechanical • Force • Mass • Torque • Hydraulic • Pressure • Flow • Thermal • Temperature • Heat flux • Convection • Electrical • Voltage • Current • Impedance • Frequency • Optical • Intensity • Wavelength (color)	• Gas • Electrochemical • Electrical conductivity • Thermal • Electrochemical • Conductimetric • Amperometric • Potentiometric • Bioanalytic • Enzyme mediated • Antigen–antibody • Ligand–receptor • Photometric • Colorimetric • Intensity • Fluorescence

Physical Sensors

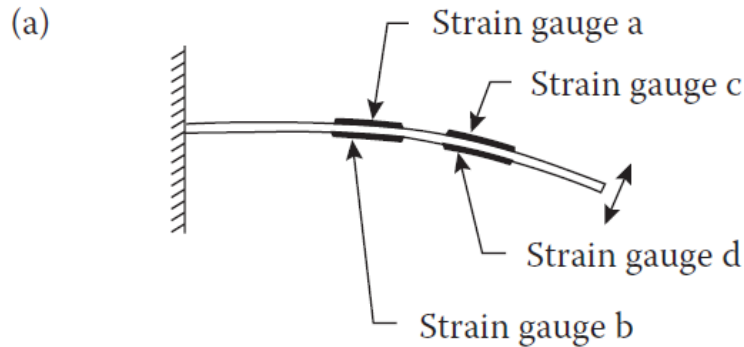
Physical Variables and Sensors

Physical Quantity	Sensor	Variable Sensed
Geometric	Strain gauge	Strain
	LVDT	Displacement
	Ultrasonic transit time	Displacement
Kinematic	Velocimeter	Velocity
	Accelerometer	Acceleration
Force–torque	Load cell	Applied force or torque
Fluidic	Pressure transducer	Pressure
	Flow meter	Flow
Thermal	Thermometer	Temperature
	Thermal flux sensor	Heat flux

Examples of displacement sensors

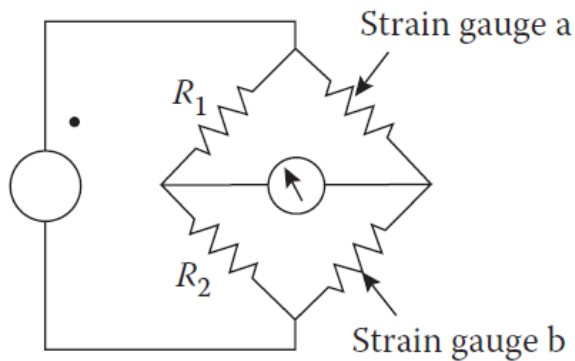


Strain gauges on a cantilever structure to provide temperature compensation



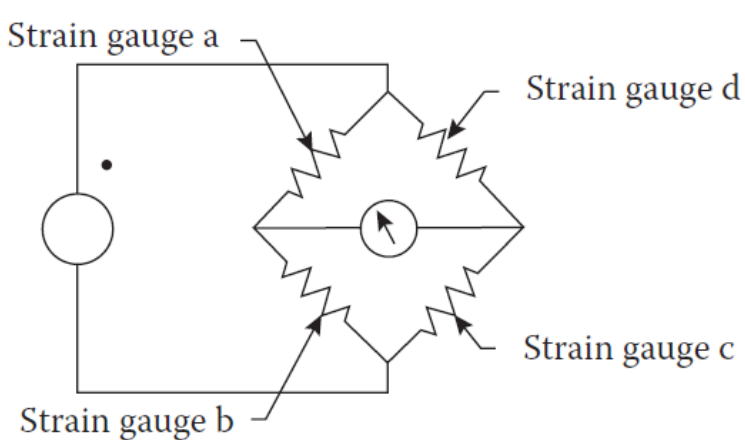
$$R = \rho \frac{L}{A}$$

(b)



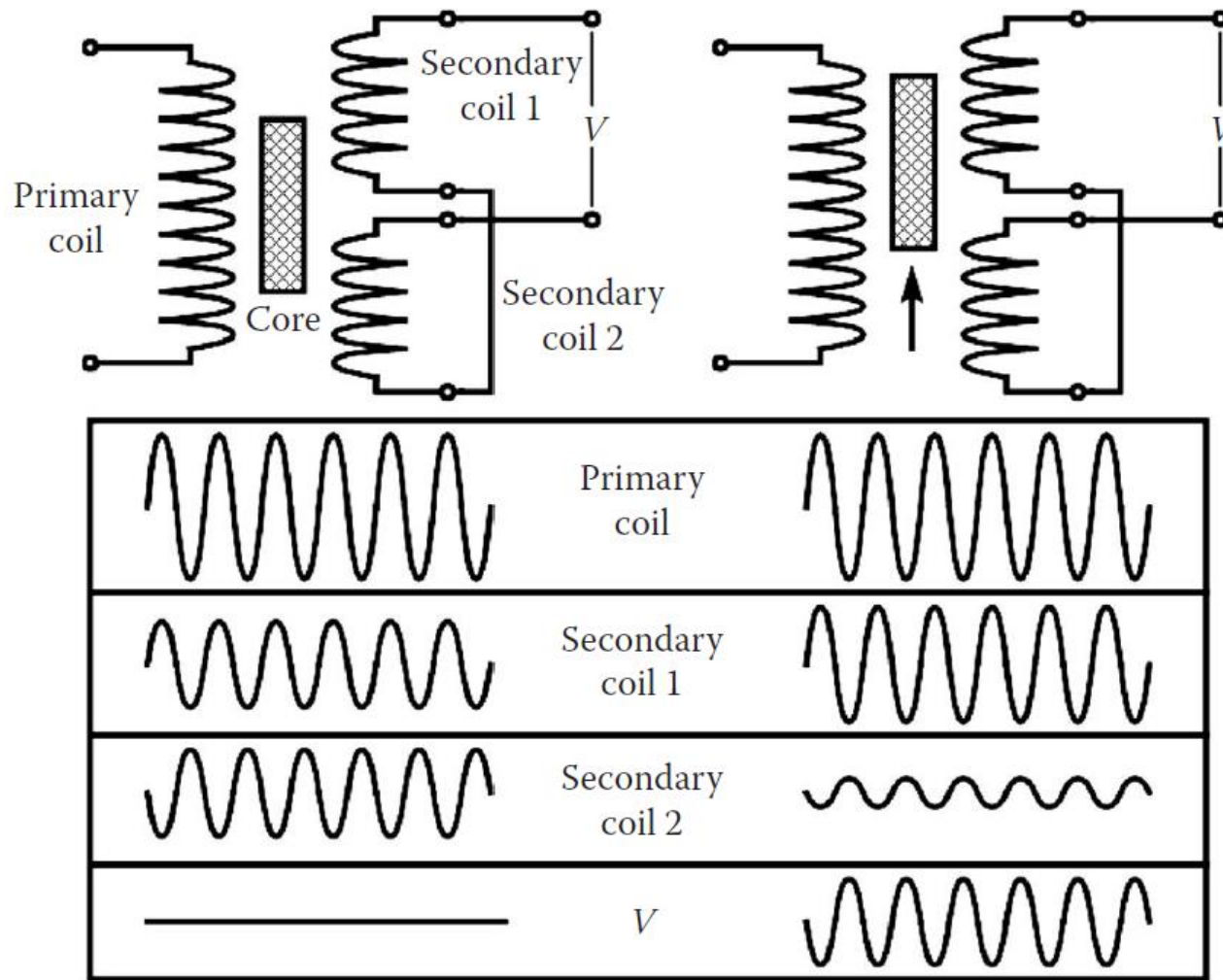
Half bridge

(c)

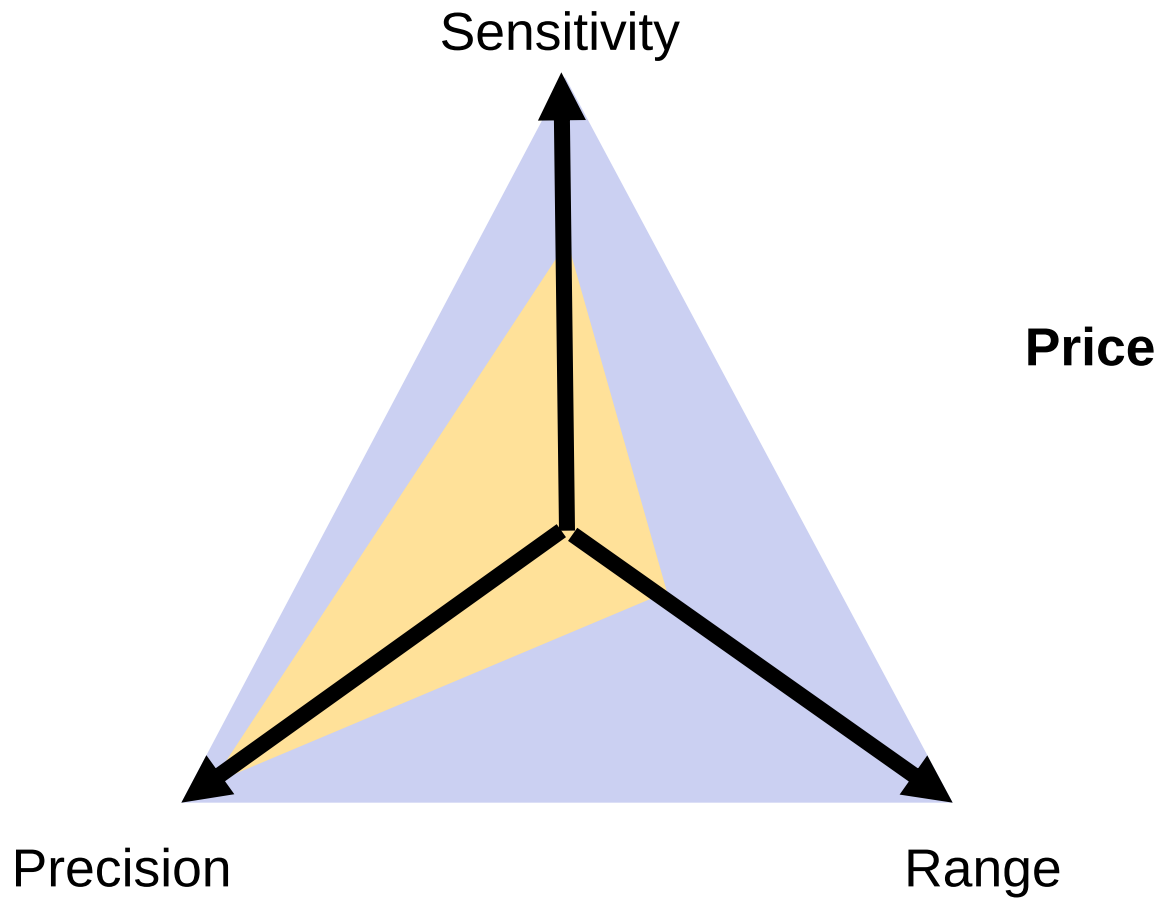


Full bridge

Linear Variable Differential Transformer



Sensor Characteristics

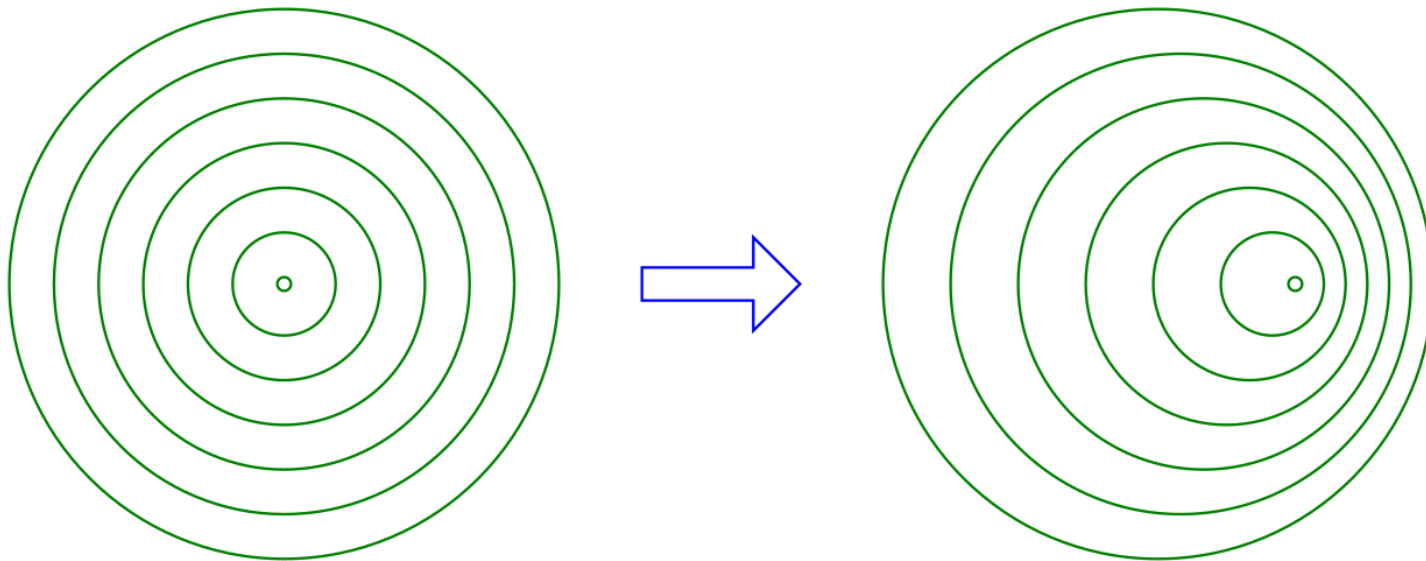


Comparison of Displacement Sensors

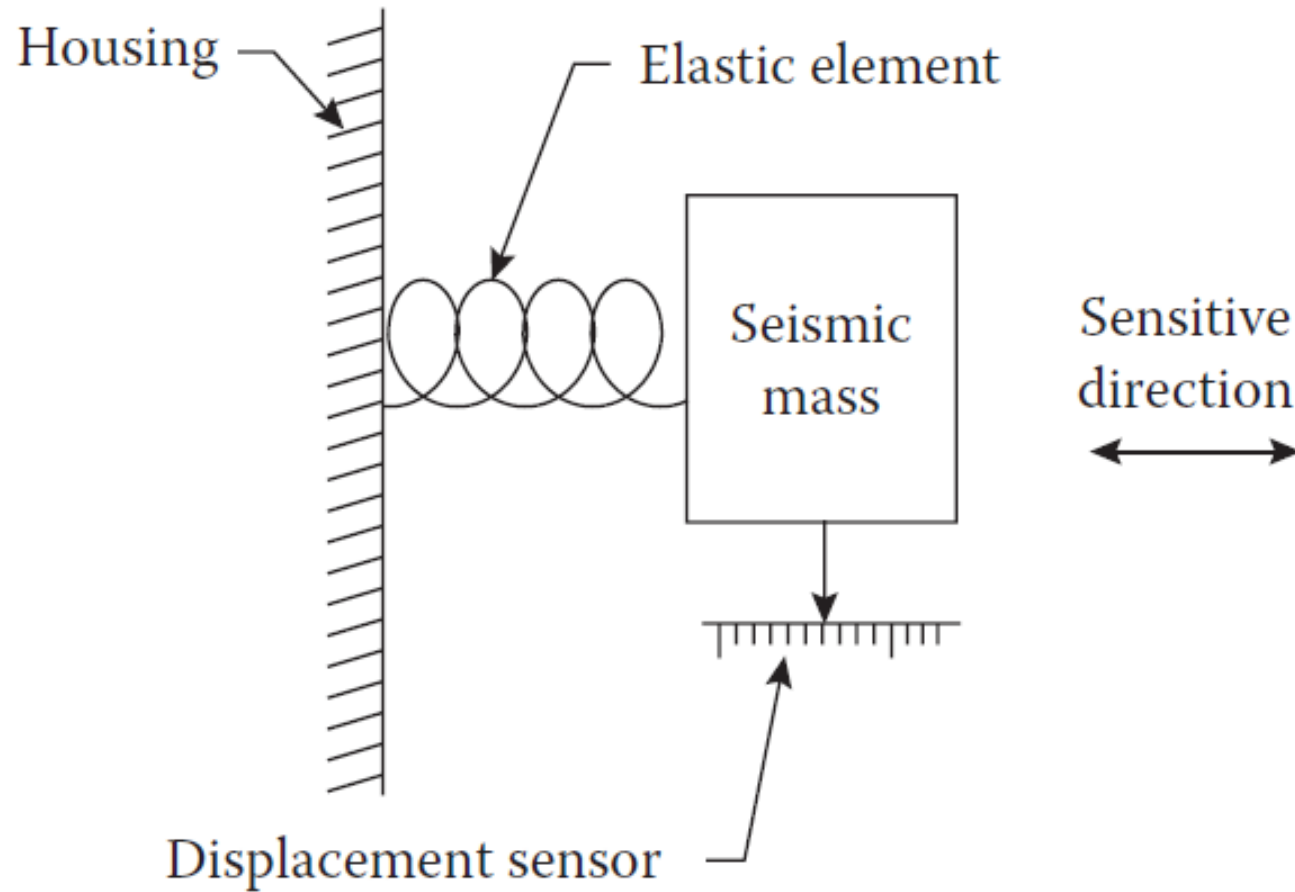
Sensor	Electrical Variable	Measurement Circuit	Sensitivity	Precision	Range
Variable resistor	Resistance	Voltage divider, ohmmeter, bridge, current source	High	Moderate	Large
Foil strain gauge	Resistance	Bridge	Low	Moderate	Small
Liquid metal strain gauge	Resistance	Ohmmeter, bridge	Moderate	Moderate	Large
Silicon strain gauge	Resistance	Bridge	High	Moderate	Small
Mutual inductance coils	Inductance	Impedance bridge, inductance meter	Moderate to high	Moderate to low	Moderate to large
Variable reluctance	Inductance	Impedance bridge, inductance meter	High	Moderate	Large
LVDT	Inductance	Voltmeter	High	High	High
Parallel plate capacitor	Capacitance	Impedance bridge, capacitance meter	Moderate to high	Moderate	Moderate to large
Sonic/ultrasonic	Time	Timer circuit	High	High	Large

Velocity Measurement

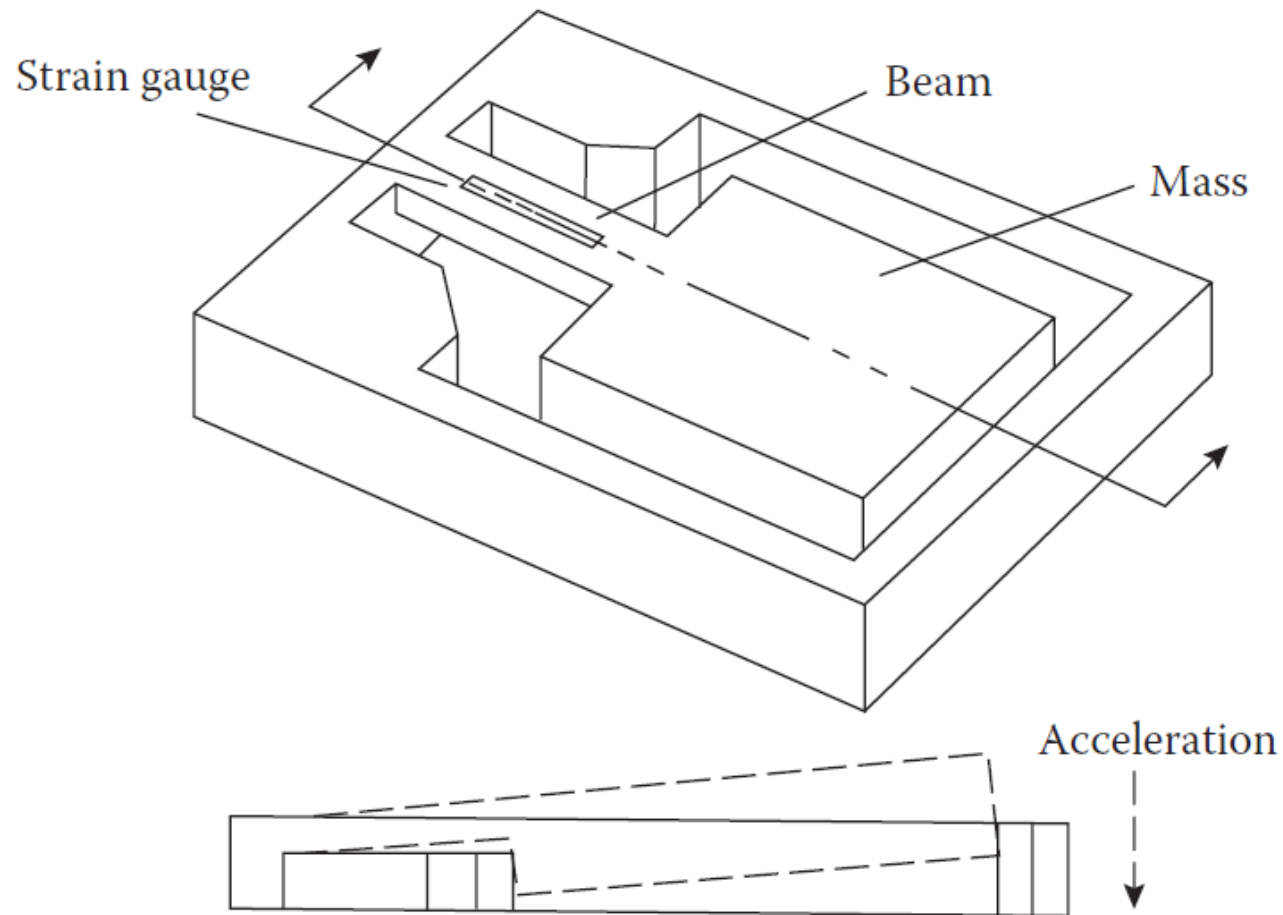
Doppler Effect (as an addition to displacement sensors)



Fundamental structure of an accelerometer



MEMS technology

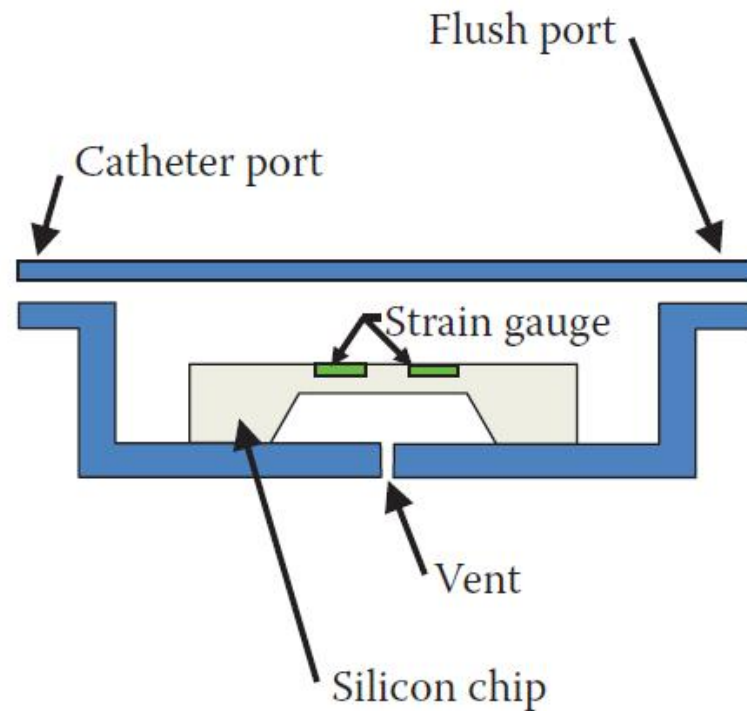


Silicon chip pressure sensors for biomedical applications

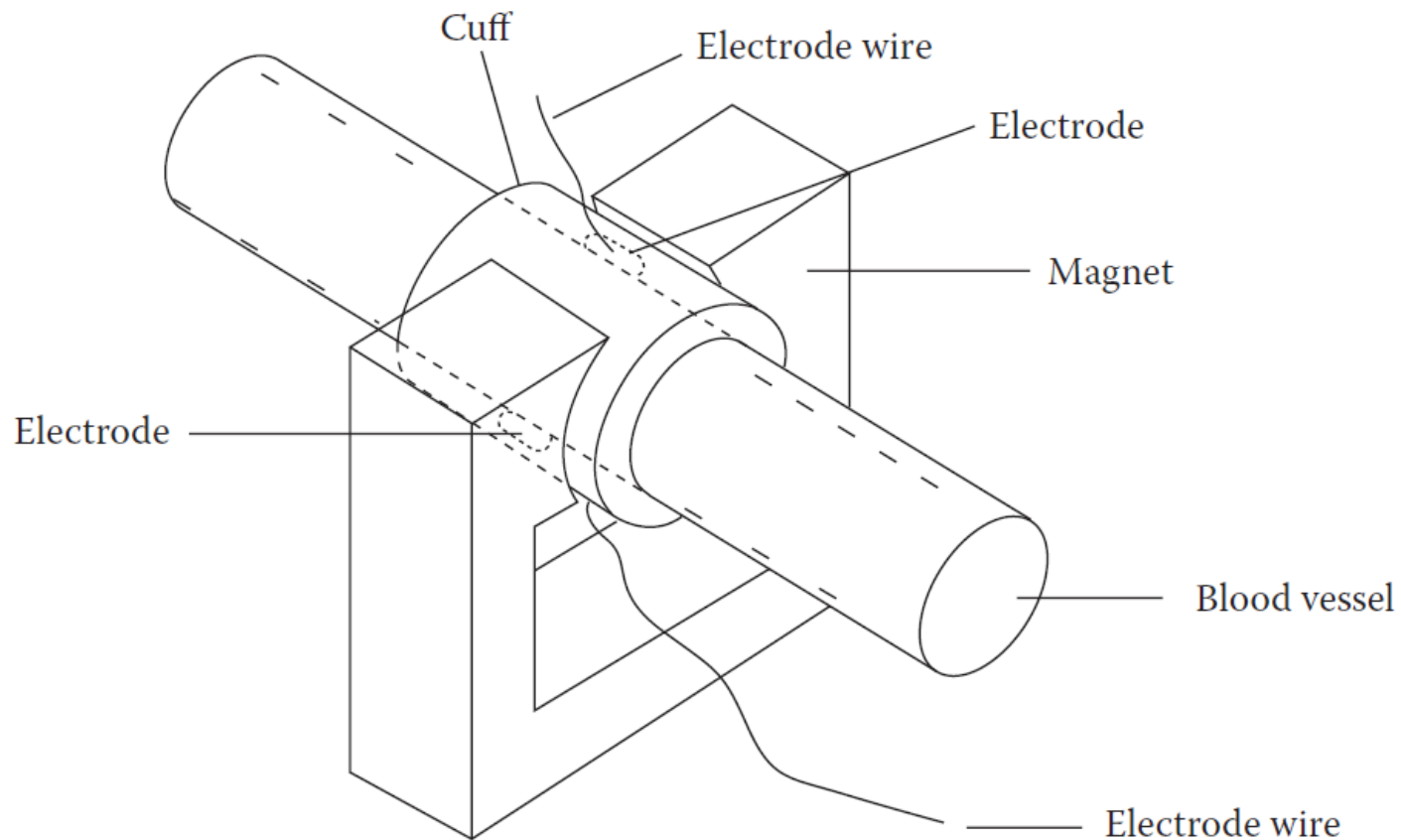
(a)



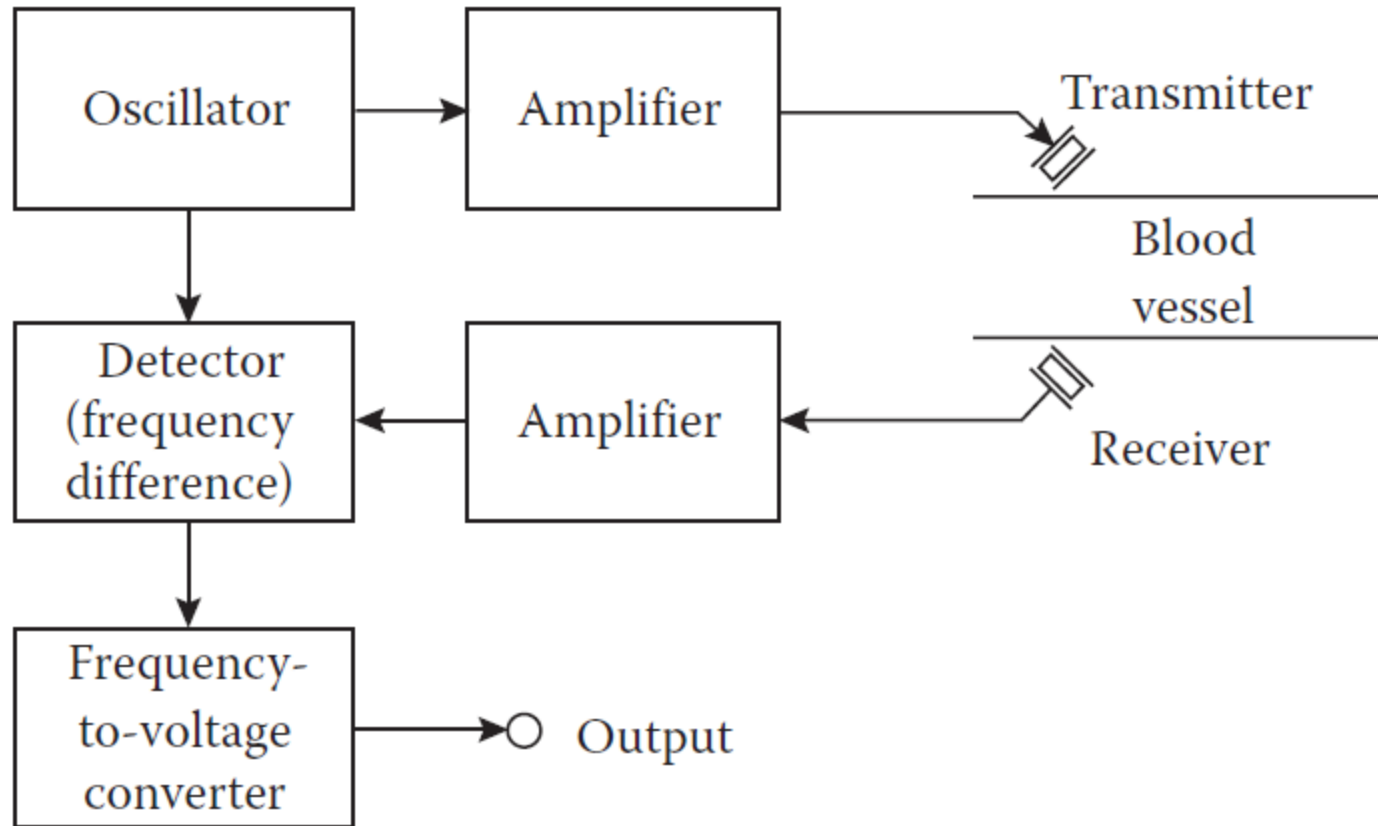
(b)



Fundamental structure of an electromagnetic flowmeter



Structure of an ultrasonic Doppler flowmeter



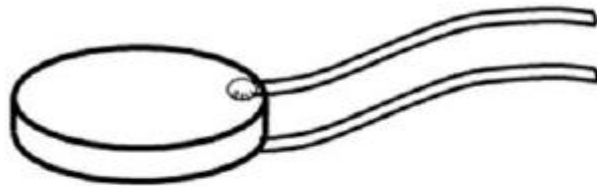
Properties of Temperature Sensors

Sensor	Form	Sensitivity	Stability	Range (°C)
Metal resistance thermometer	Coil of fine platinum wire	Low	High	−100 to 700
Thermistor	Bead, disk, chip, or rod	High	Moderate	−50 to 150
Thermocouple	Pair of wires	Low	High	−100 to >1500
Mercury in glass thermometer	Column of Hg in glass capillary	Moderate	High	−50 to 400
Silicon $p-n$ diode	Electronic component	Moderate	High	−50 to 150

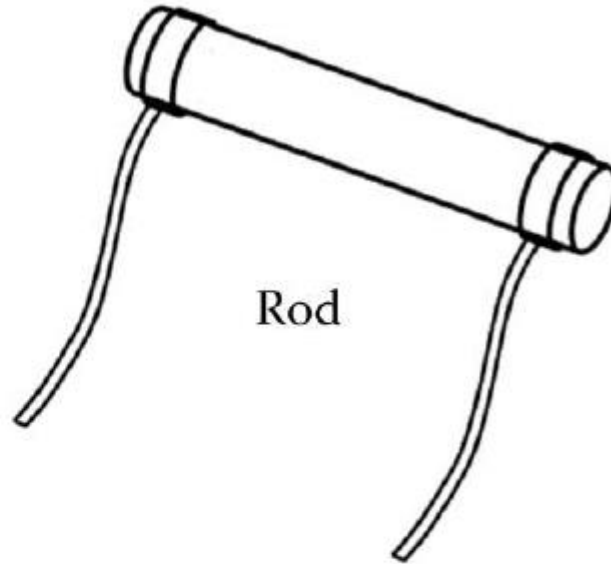
Temperature Coefficient of Resistance

Metal or Alloy	Resistivity at 20°C ($\mu\Omega$ cm)	Temperature Coefficient of Resistance (%/°C)
Platinum	9.83	0.3
Gold	2.22	0.368
Silver	1.629	0.38
Copper	1.724	0.393
Constantan (60% Cu, 40% Ni)	49.0	0.0002
Nichrome (80% Ni, 20% Cr)	108.0	0.013

Common commercially available forms for thermistors



Disk



Rod

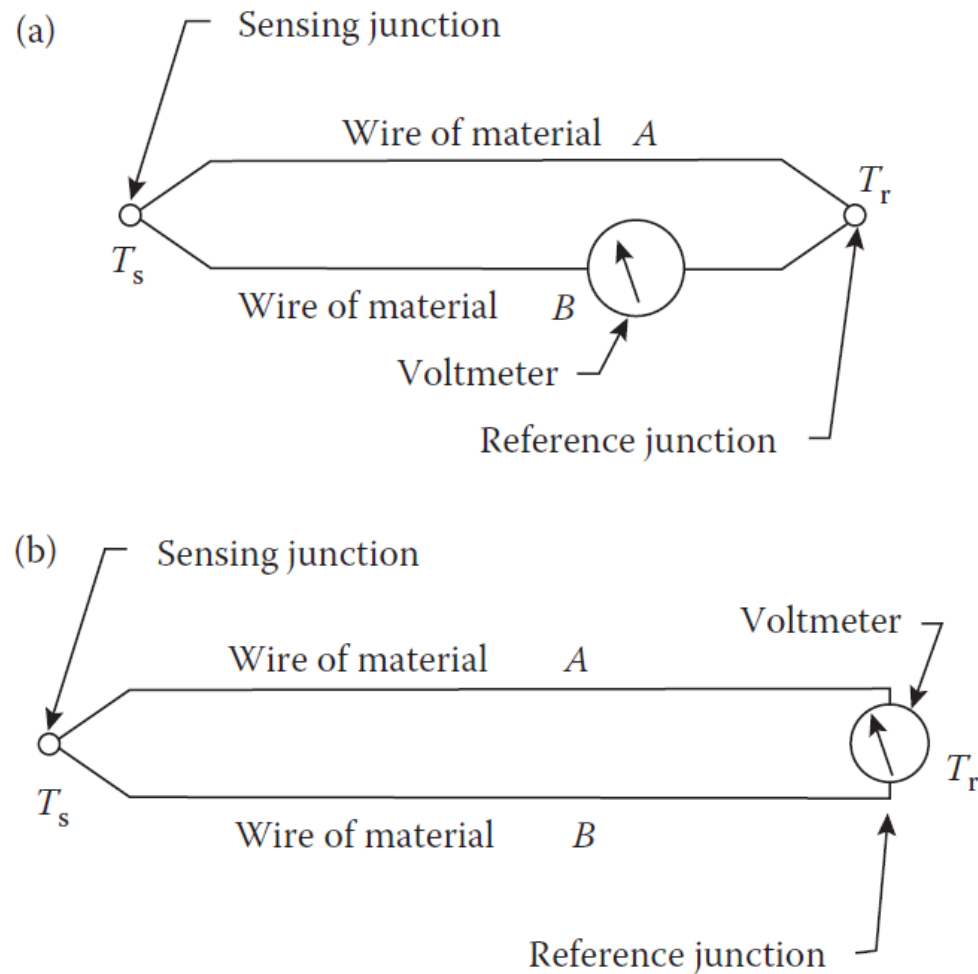


Bead



Chip

Circuit arrangement for a thermocouple



Common Thermocouples

Type	Materials	Seebeck Coefficient ($\mu\text{V}/^\circ\text{C}$) ^a	Temperature Range ($^\circ\text{C}$)
S	Platinum/platinum 10% rhodium	6	0 to 1700
T	Copper/constantan	50	−190 to 400
K	Chromel/alumel	41	−200 to 1370
J	Iron/constantan	53	−200 to 760
E	Chromel/constantan	78	−200 to 970

Examples of Biomedical Applications of Physical Sensors

Sensor	Application	Signal Range
Liquid metal strain gauge	Breathing movement	0–0.05 (strain)
	Limb plethysmography	0–0.02 (strain)
Magnetic displacement sensor LVDT	Breathing movement	0–10 mm
	Muscle contraction	0–20 mm
	Uterine contraction sensor	0–5 mm
Load cell	Electronic scale	0–440 lbs (0–200 kg)
Accelerometer	Subject activity	0–20 m/s ²
Miniature silicon pressure sensor	Intraarterial blood pressure	0–50 Pa (0–350 mmHg)
	Urinary bladder pressure	0–10 Pa (0–70 mmHg)
	Intrauterine pressure	0–15 Pa (0–100 mmHg)
Electromagnetic flow sensor	Cardiac output (with integrator)	0–500 mL/min
	Organ blood flow	0–100 mL/min

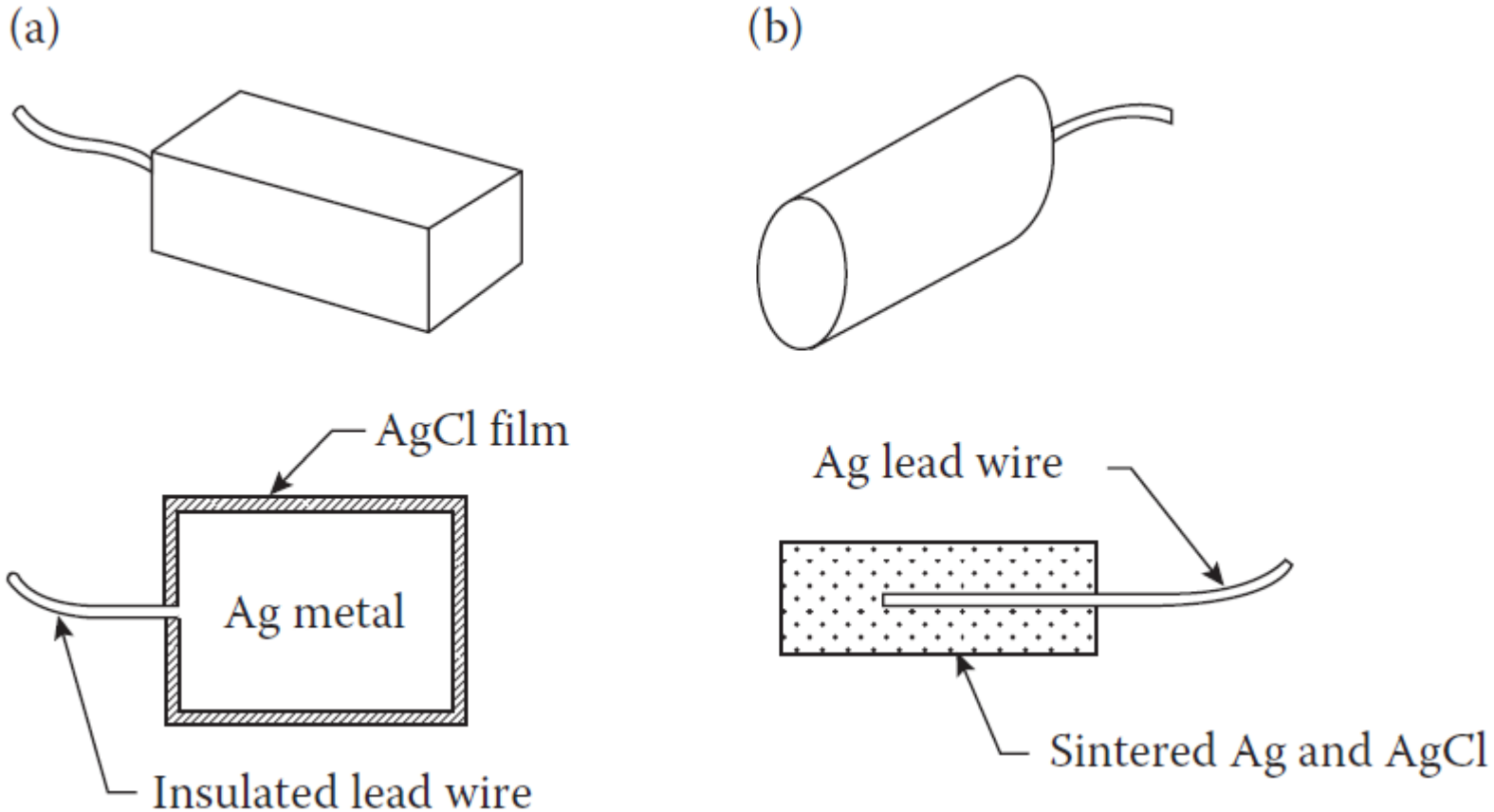
Bipotential Electrodes

Bioelectric Signals Sensed by Biopotential Electrodes

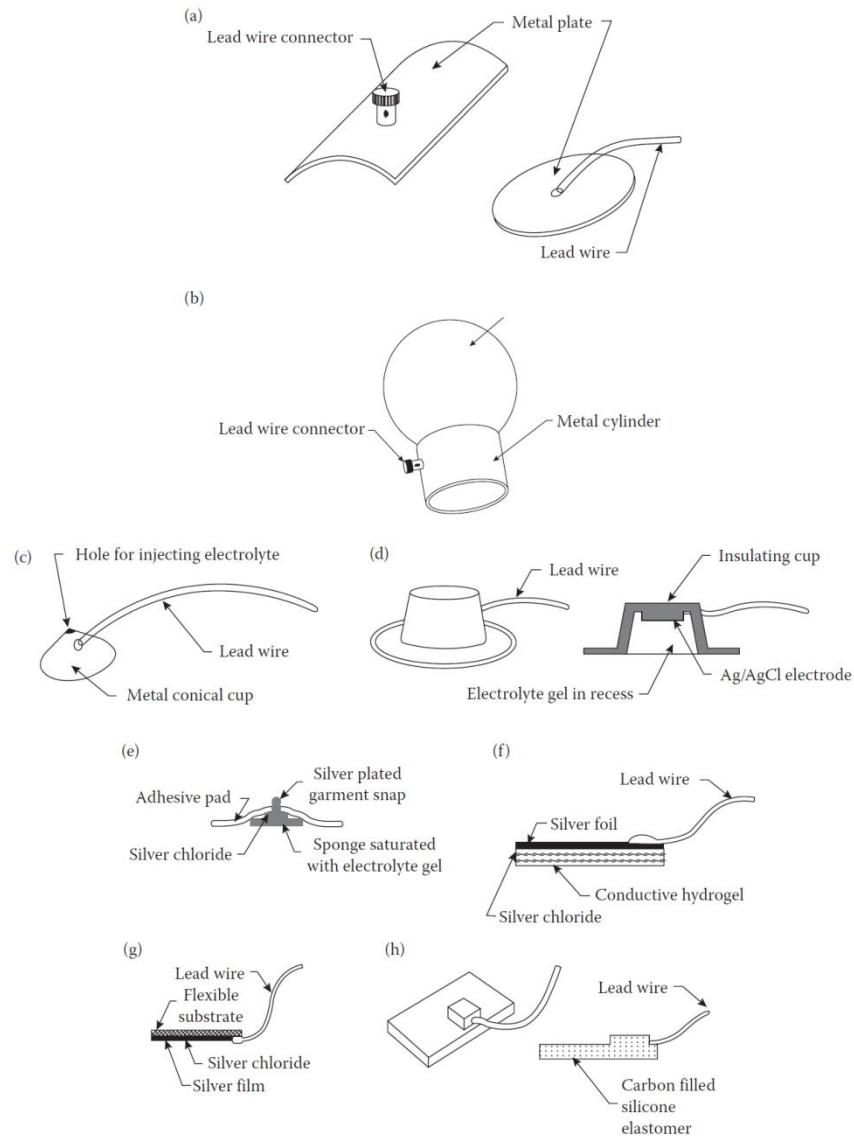
Metal and Reaction	Half-Cell Potential (V)
$\text{Al} \rightarrow \text{Al}^{3+} + 3\text{e}^-$	-1.706
$\text{Ni} \rightarrow \text{Ni}^{2+} + 2\text{e}^-$	-0.230
$\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$	0.000 (by definition)
$\text{Ag}^+\text{Cl}^- \rightarrow \text{AgCl} + \text{e}^-$	+0.223
$\text{Ag} \rightarrow \text{Ag}^+ + \text{e}^-$	+0.799
$\text{Au} \rightarrow \text{Au}^+ + \text{e}^-$	+1.680

$$E = E^0 - \frac{RT}{nF} \ln(a)$$

Bioelectric Signals Sensed by Biopotential Electrodes



Skin Electrodes

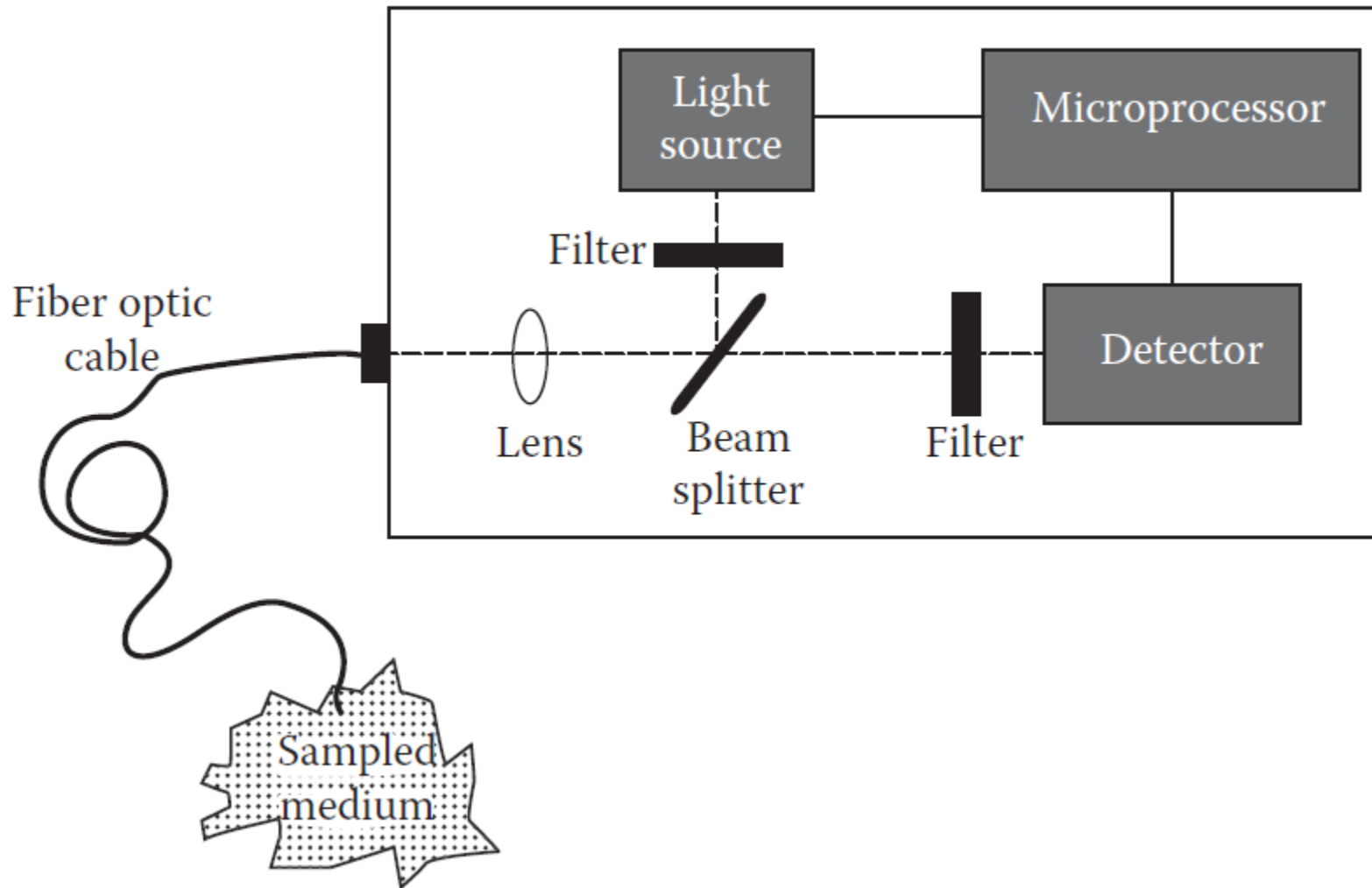


Bioelectric Signals Sensed by Biopotential Electrodes and Their Sources

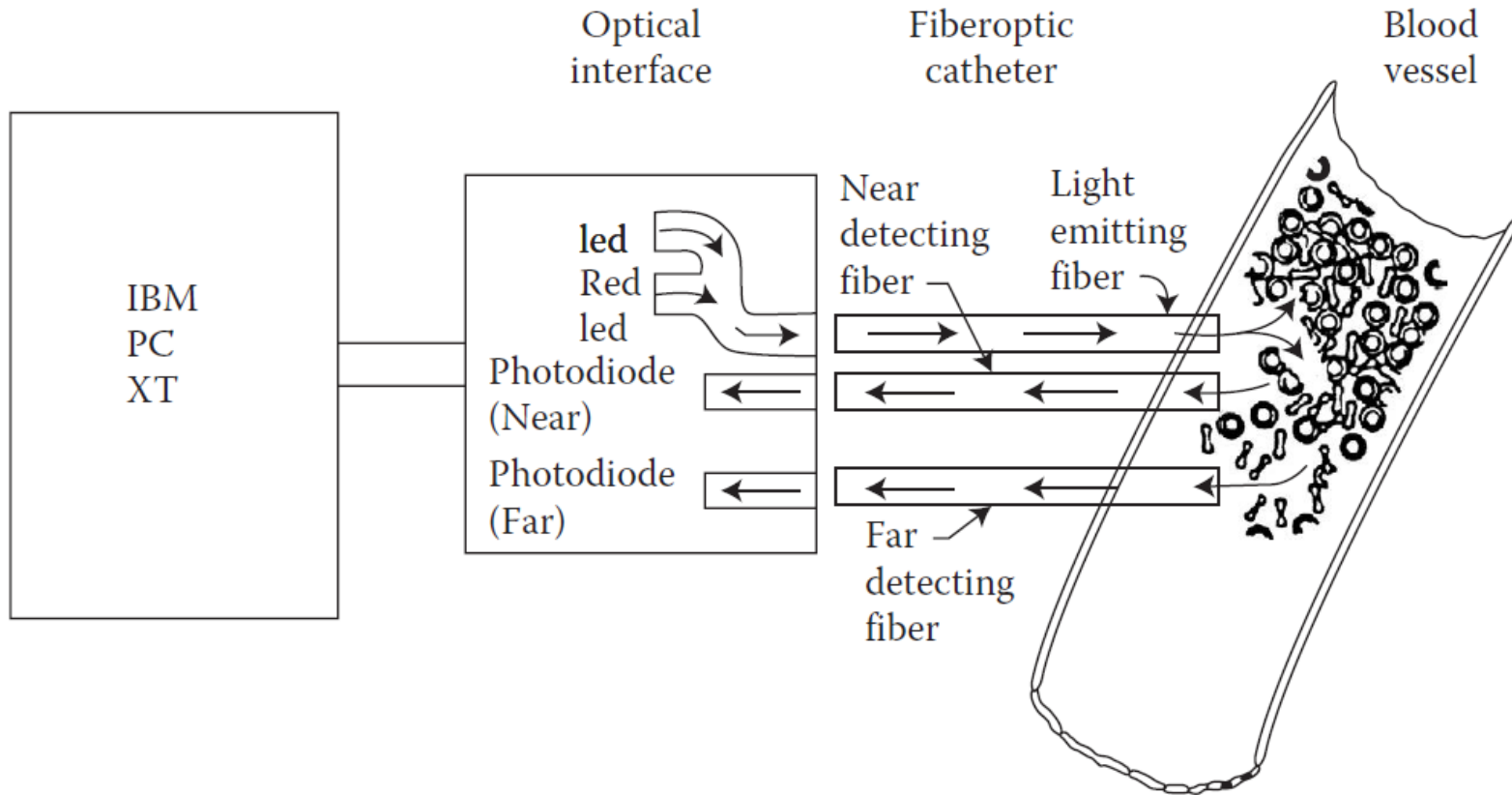
Application	Biopotential	Type of Electrode
Cardiac monitoring	ECG	Ag/AgCl with sponge Ag/AgCl with hydrogel
Infant cardiopulmonary monitoring	ECG impedance	Ag/AgCl with sponge Ag/AgCl with hydrogel Thin film Filled elastomer dry
Sleep encephalography	EEG	Gold cups Ag/AgCl cups Active electrodes
Diagnostic muscle activity	EMG	Needle
Cardiac electrograms	Electrogram	Intracardiac probe
Implanted telemetry of biopotentials	ECG	Stainless-steel wire loops
	EMG	Platinum disks
Eye movement	EOG	Ag/AgCl with hydrogel

Optical Sensors

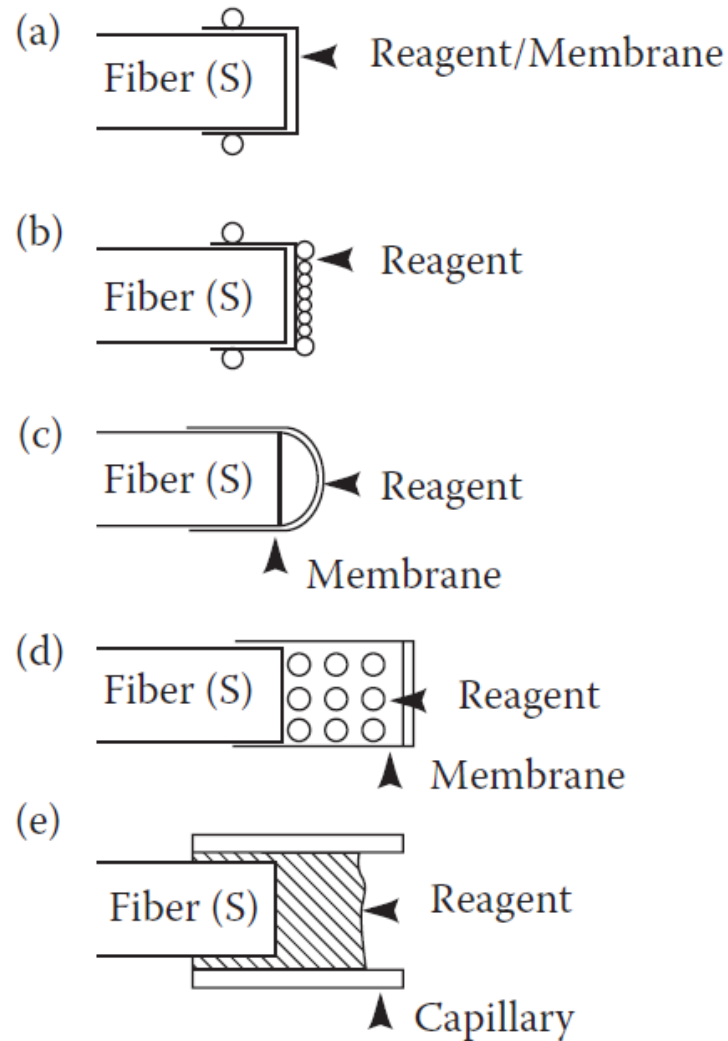
General Diagram Optical Instrument



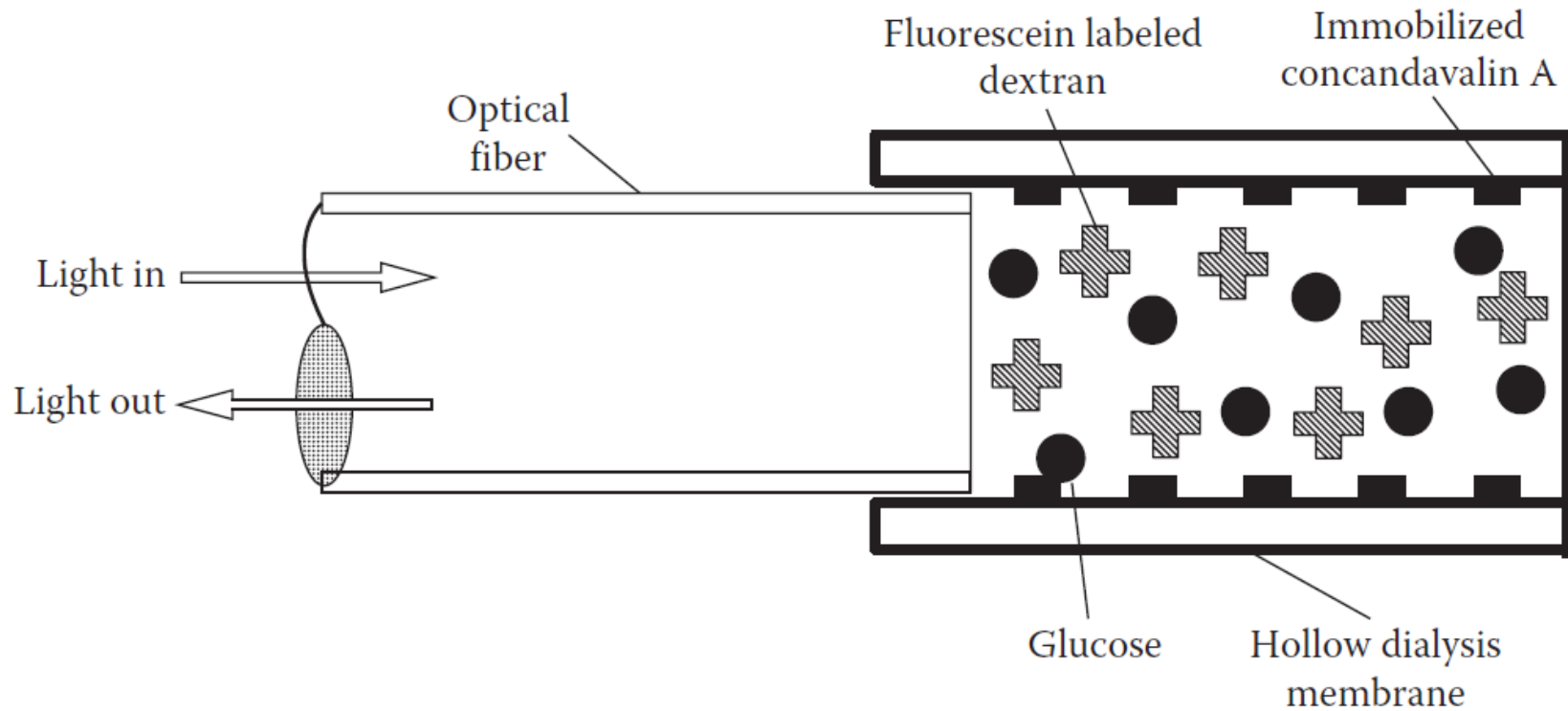
Fiber Optic Sensors Oxygen Saturation



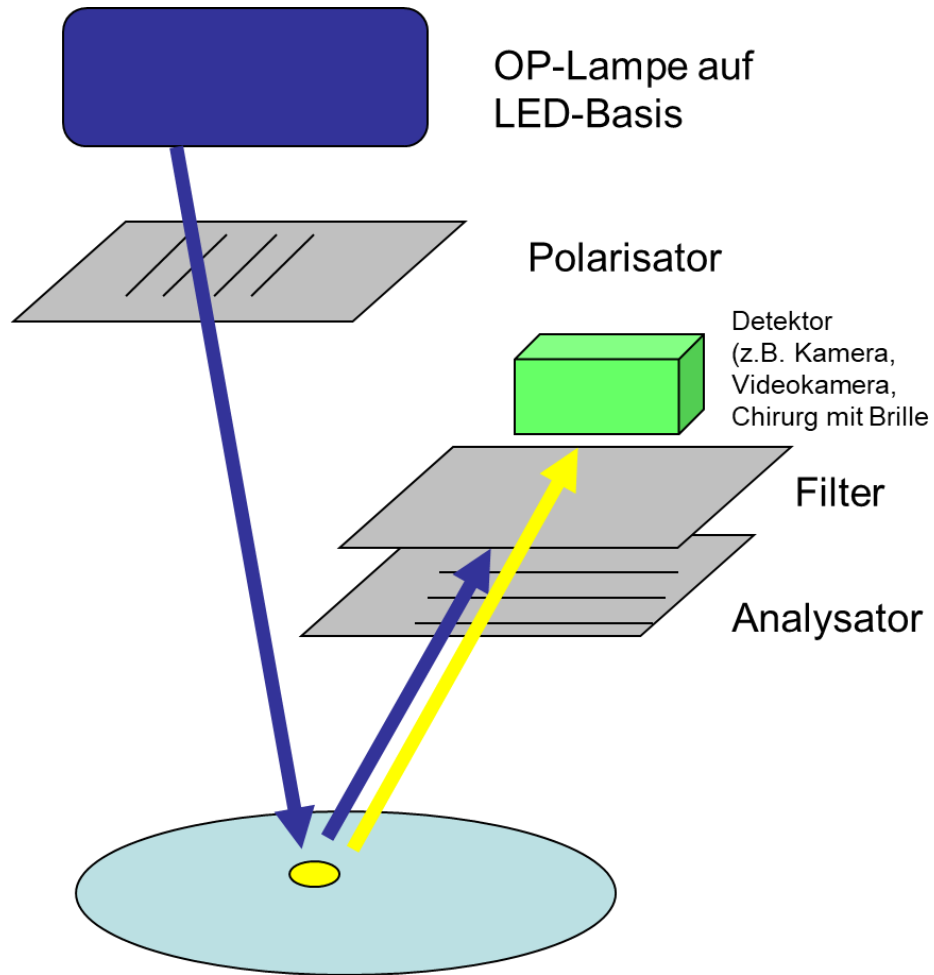
Indicator-mediated Fiber Optic Sensors



Indicator-mediated Fiber Optic Sensors



Some own Research



Some own Research



Some own Research

