Sydney Institute of Technology

School of Electrotechnology

Industrial Electronics

Industrial Sensors

Learners Theory Work Book

This material is for use in conjunction with class presentation by the Department of Industrial Electronics

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Industrial Sensors

1. Introduction

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Transducer performance characteristics

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Theory Notes

Area ____________________

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SUMMARY

- Electrical input transducers and sensors are classified according to the physical variables to which they are sensitive. The four main categories are thermal, optical, magnetic, and electromechanical. The following tables give a brief summary of the operating characteristics of the transducers and sensors discussed in this chapter.

Thermal Transducers

	Operation	*Advantages*	*Disadvantages*
Thermistor	Device resistance changes inversely with variations in temperature.	Large nominal *R* Large *R* variation Inexpensive Fast	Nonlinear Narrow temperature range Requires power Self-heats
RTD	Device resistance changes directly with variations in temperature.	Linear *R* variation Most stable Most accurate	Expensive Small *R* variation Requires power
Thermocouple	Device produces voltage or current proportional to temperature.	Nearly linear output Wide temperature range Used at high temperatures Self-powered	Low output Least sensitive Requires reference

Temperature Sensors

	Operation	*Advantages*	*Disadvantages*
IC Temperature Sensor	Device produces voltage or current numerically equivalent to absolute temperature.	Linear output Small packages Inexpensive Fast	Low temperature range Low output
Temperature Transmitter	Device accepts thermocouple or RTD input. Output current is proportional to temperature.	Linear output Facilitates remote sensing	Accepts only thermocouples or RTDs as inputs
Optical Pyrometer	Focuses infrared energy on IC temperature sensor in probe. Output current is proportional to temperature.	Linear output Used at high temperatures Noncontact	Expensive

Optical Transducers

	Operation	*Advantages*	*Disadvantages*
Photoconductive Cell	Device resistance changes inversely with variations in EMR intensity.	Large *R* variation	Slow response Requires power Temperature sensitive
Photovoltaic (Solar) Cell	Converts EMR into electrical current. Current is proportional to EMR intensity.	Self-powered Linear output current	Large surface area Inefficient Slow response Nonlinear output voltage
Photodiode	Converts EMR into electrical current. Current is proportional to EMR intensity.	Small Fast	Low output Requires external power supply
Phototransistor	Converts EMR into current, which is injected into the base. Device then responds as typical transistor.	Sensitive High output Fast	Requires external power supply

Optical Sensing Methods

	Operation	*Advantages*	*Disadvantages*
Opposed Sensing	EMR beam is directed from transmitter to receiver. Object is detected when beam is interrupted.	Long sensing range	Transmitter and receiver must be precisely aligned. Separate receiver and transmitter required
Retroreflective Sensing	EMR beam is directed from transmitter to a reflector and back to receiver. Object is detected when beam is interrupted.	Transmitter and receiver may be housed in the same unit.	Sensing range limited to about 30 ft Requires remote reflector
Diffuse Sensing	EMR beam is directed at sensed object, which acts as reflector. Object is sensed when beam is reflected back to receiver.	Transmitter and receiver may be housed in the same unit. No reflector required	Sensing range limited to less than 10 ft Sensed object must be reflective.

Electromechanical Transducers

	Operation	*Advantages*	*Disadvantages*
Limit Switch	Electrical contact is maintained or broken according to position of actuator.	Usually requires no external power supply Available in a variety of styles	Must contact the sensed object
Potentiometer	Resistance (or voltage) between wiper and either terminal changes as shaft is turned.	Durable	Requires external power supply Requires some sort of gearing or linkage
Wire Strain Gauge	Device resistance changes as gauge is compressed or elongated.	Durable	Requires external power supply Low gauge factor
Semiconductor Strain Gauge	Device resistance changes as gauge is compressed or elongated.	High gauge factor	Requires external power supply

Magnetic Transducers

	Operation	*Advantages*	*Disadvantages*
Inductive	Relative motion of magnetic field and coil induces voltage in coil.	Requires no power supply	Detects motion only
Reluctive	Proximity of a low-reluctance object alters magnetic field surrounding device and induces voltage in coil.	Requires no power supply	Detects motion only
Hall-Effect	Presence of a magnetic field produces voltage proportional to strength of field.	Senses stationary fields Inexpensive	Requires external power supply

Flow Sensors (*continued*)

	Operation	*Advantages*	*Disadvantages*
Ultrasonic	Acoustic energy is transmitted upstream into fluid, at a given frequency. Frequency of reflected energy is proportional to fluid velocity.	No moving parts Flow may be sensed through pipe walls. Does not impede fluid flow	Most expensive
Magnetic	Voltage is induced in fluid as it passes through magnetic field. Electrodes sense voltage, which is proportional to flow.	No moving parts Relatively inexpensive Does not impede fluid flow	Fluid must be electrically conductive.

Level Sensors

	Operation	*Advantages*	*Disadvantages*
Float	When rising liquid level reaches float, float rises and actuates either a magnetic or a mechanical switch.	Inexpensive	Senses liquids only
Conductive Probe	When rising liquid level contacts the probes, current flows and is available at output.	No moving parts Inexpensive	Senses liquids only Liquid must be electrically conductive.
Ultrasonic Contact	Acoustic energy is directed across a gap toward receiver. Liquid within gap completes transmission path.	No moving parts Senses any liquid	Expensive
Ultrasonic Noncontact	Acoustic energy is transmitted toward surface to be sensed. Reflection time determines surface distance.	No moving parts Surface contact not required Measures absolute height	Most expensive

Level Sensors (*continued*)

	Operation	*Advantages*	*Disadvantages*
Proximity	Frequency change in oscillator indicates object proximity. Output is activated when oscillator changes frequency.	No moving parts	Sensing range limited to about 10 cm

Flow Sensors

	Operation	*Advantages*	*Disadvantages*
Turbine	Fluid flowing past turbine causes blades to spin. Rotation is detected by magnetic sensor.	Relatively inexpensive	Impedes fluid flow
Vortex	As fluid flows past a vortex shedder, vortices are produced downstream. Resultant vibrations are sensed piezoelectrically.	Minimal moving parts Accurate	Expensive Impedes fluid flow
Thermal	Probe is heated to constant temperature. Thermal transducer measures rate of cooling, which is proportional to flow rate.	No moving parts Relatively inexpensive	Slow response Impedes fluid flow Fluid must be thermally conductive.

8.7 Glossary of Terms

Alignment
Transmitter and receiver of thru-beam units should be properly aligned along a common axis, otherwise sensitivity is reduced.
Maximum intensity of the radiated energy is obtained when the axis of the radiated light hits the view field of the receiver.

Amplifier
A device or circuit which amplifies signals. The control unit which supplies DC power and solid-state output or relay-drive output.

Amplifier Built-in Sensor
Amplifier is incorporated in the sensor unit, which brings the unit to supply relay-drive or solid-state output.

Amplifier-separated Sensor
A sensor without an amplifer in it but only a light emitting and receiving element. For sensing operation, the sensor has to be combined to either amplifer or control unit.

Contact Output
Output is obtained in the form of relay contact output.

Cross Beam
The optical lens are aligned in such a manner that the emitted light beam axis and the reflected light axis cross each other. This enables a sensing area to be limited in some field at a certain distance from the tip of a sensor. The advantage of this is that the sensor cannot be influenced by the reflection from the background of an object.

Dark Mode
The output of the sensor is energised when no light falls on the receiver.

Effective Beam Diameter
The effective beam diameter is the 'core' of the beam in which the receiver, the reflector or the target may be placed to operate.

External Synchronisation
A sensing signal is controlled in timing with other signals coming from outside.

Extraneous Light
Ambient light which affects the operation of a beam sensor.

Hysterisis
Distance between turn-on and turn-off points of a sensor when an object is detected.

Infa-red (I.R.)
An invisible light beyond the range of the visible spectrum in the red region.

Input or Supply Voltage
Operating voltage required to sufficiently maintain power to a device.

Mark Sensor
Sensor designed to detect marks and/or colour tones on the surface of objects.

Modulated Light
The infa-red LED is pulsed rapidly at a specific frequency so that the photodetector turned to the same pulse frequency, detects only the desired light source, reducing interference from ambient light.

Non-contact Voltage Output
Output voltage generated in either NPN or PNP solid-state output circuit.

Operating Mode / Switch Mode
State of sensor which energises the output. Light 'On' or Dark-'On' is selected with an operation mode selector.

Operating Range
Maximum distance in which the target can be detected from the photoelectric sensor. (Example: Maximum distance between emitter-receiver or sensor and target, or sensor and reflector.)

Optic-Fibre
Glass or plastic fibre enables to transmit and lead a light beam to form Thru-beam or Proximity scanning.

Output
A switching device which opens or closes a circuit enabling or disabling current flow.

Output Mode
Indicates in what forms an output is obtained: relay output or solid-state output.

Output Rating
Maximum contact capacity of a relay or limit value of voltage/current of a solid-state output circuit.

Repeatability / Repeat Accuracy
The accuracy of a sensor to detect an object repeatedly.

Response Time
The time required between the presense of the target (presence or absense of received beam) and the corresponding output change.

Self-Contained Beam Sensor
A beam sensor which has power supply, signal conditioning and output in one enclosure. The opposite of this type of beam sensor is component systems which have sources and detectors remote from power.

Slot Sensor
A U-frame scanner with opposing emitter and receiver in the same unit. May be used for small object detection revolution counting, notch/space detection on toothed wheels, thread break detection and edge guide control.

Timing
A method of enhancing or varying a signal. May be used to delay an output from energising, or to keep an output energised longer.

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CONVERSION TABLES

Length

	mm	cm	m	in	ft	yd	km	mile
mm	1	10^{-1}	10^{-3}	3.937×10^{-2}	3.280×10^{-3}	1.093×10^{-3}	10^{-6}	6.213×10^{-7}
cm	10	1	10^{-2}	3.937×10^{-1}	3.280×10^{-2}	1.093×10^{-2}	10^{-5}	6.213×10^{-6}
m	1000	100	1	39.3701	3.280 84	1.093 61	$\times 10^{-3}$	6.213×10^{-4}
in	25.4	2.54	2.54×10^{-2}	1	8.333×10^{-2}	2.777×10^{-2}	2.54×10^{-5}	1.578×10^{-5}
ft	304.8	30.48	3.048×10^{-1}	12	1	3.333×10^{-1}	3.048×10^{-4}	1.893×10^{-4}
yd	914.4	91.44	9.144×10^{-1}	36	3	1	9.144×10^{-4}	5.681×10^{-4}
km	10^{6}	10^{5}	1000	39 370.1	3280.84	1093.61	1	6.213×10^{-1}
mile	1.609×10^{6}	160 934	1609.34	63 360	5280	1760	1.609	1

Area

	cm^2	m^2	are	hectare	km^2	in^2	ft^2	yd^2	$mile^2$	acre
cm^2	1	10^{-4}	10^{-6}	10^{-8}	10^{-10}	1.55×10^{-1}	1.076×10^{-3}	1.196×10^{-4}	3.861×10^{-11}	2.471×10^{-8}
m^2	10 000	1	10^{-2}	10^{-4}	10^{-6}	1550	10.7639	1.195 99	3.861×10^{-7}	2.471×10^{-4}
are	10^{6}	100	1	10^{-2}	10^{-4}	155 000	1076.39	119.599	3.861×10^{-5}	2.471×10^{-2}
hectare	10^{8}	10 000	100	1	10^{-2}	1.55×10^{7}	107 639	11 959.9	3.861×10^{-3}	2.471 05
km^2	10^{10}	10^{6}	10 000	100	1	1.55×10^{9}	1.076×10^{7}	1.196×10^{6}	3.861×10^{-1}	247.105
in^2	6.4516	6.4516×10^{-4}	6.4516×10^{-6}	6.4516×10^{-8}	6.4516×10^{-10}	1	6.944×10^{-3}	7.716×10^{-4}	2.491×10^{-10}	1.594×10^{-7}
ft^2	929.03	9.2903×10^{-2}	9.2903×10^{-4}	9.2903×10^{-6}	9.2903×10^{-8}	144	1	$1.111 1 \times 10^{-1}$	3.587×10^{-8}	2.295×10^{-5}
yd^2	8361.27	$8.361 27 \times 10^{-1}$	$8.361 27 \times 10^{-3}$	$8.361 27 \times 10^{-5}$	$8.361 27 \times 10^{-7}$	1296	9	1	3.228×10^{-7}	2.066×10^{-4}
$mile^2$	2.589×10^{10}	2.589×10^{6}	25 899.9	258.999	2.589 99	4.014×10^{9}	2.787×10^{7}	2.0976×10^{6}	1	640
acre	4.046×10^{7}	4046.86	40.4686	$4.046 86 \times 10^{-1}$	$4.046 86 \times 10^{-3}$	6.272×10^{6}	43 560	4840	1.5625×10^{-3}	1

Volume

	cm^3	dm^3 (= litre)	in^3	ft^3	yd^3	US fl oz	Imp fl oz	US gal	Imp gal	Imp pint
cm^3	1	10^{-3}	6.102×10^{-2}	3.531×10^{-5}	1.308×10^{-6}	3.3814×10^{-2}	3.519×10^{-2}	2.641×10^{-4}	2.199×10^{-4}	1.759×10^{-3}
dm^3 (= litre)	1000	1	61.0237	3.531×10^{-2}	1.308×10^{-3}	33.814	35.1951	2.641×10^{-1}	2.199×10^{-1}	1.759 75
in^3	16.3871	1.638×10^{-2}	1	5.787×10^{-4}	2.143×10^{-5}	5.541×10^{-1}	5.767×10^{-1}	4.329×10^{-3}	3.604×10^{-3}	2.883×10^{-2}
ft^3	28 316.8	28.3168	1728	1	3.7037×10^{-2}	957.506	996.614	7.480 52	6.228 84	49.8307
yd^3	764 555	764.555	46 656	27	1	25 852.7	26 908.6	201.974	168.179	1345.43
US fl oz	29.5735	2.957×10^{-2}	1.804 69	1.044×10^{-3}	3.868×10^{-5}	1	1.040 84	7.8125×10^{-3}	6.505×10^{-3}	5.204×10^{-2}
Imp fl oz	28.4131	2.841×10^{-2}	1.733 87	1.003×10^{-3}	3.716×10^{-5}	9.6076×10^{-1}	1	7.506×10^{-3}	6.25×10^{-3}	5×10^{-2}
US gal	3785.41	3.785 41	231	1.336×10^{-1}	4.951×10^{-3}	128	133.228	1	8.326×10^{-1}	6.661 39
Imp gal	4546.09	4.546 09	277.149	1.605×10^{-1}	5.946×10^{-3}	153.772	160	1.200 95	1	8
Imp pint	568.261	5.682×10^{-1}	34.6774	2.0068×10^{-2}	7.432×10^{-4}	19.2152	20	1.501×10^{-1}	1.25×10^{-1}	1

1 SI UNITS & SYMBOLS

The following formulae are based on the International System of Units, known as SI (Système Internationale d'Unités) which is used throughout this book. SI was adopted in February 1969 by a resolution of the CGPM (Conférence Générale de Poids et Mésures) as ISO Recommendation R1000.

A base unit exists for each of the dimensionally independent physical quantities: length, mass, time, electric current, thermodynamic temperature and luminous intensity. The SI unit of any other quantity may be derived by appropriate simple multiplication or division of the base units without the introduction of numerical factors.

The system is independent of the effects of gravity, making a clear distinction between the mass of a body (unit of mass = kilogram) and its weight, ie the force due to gravity (unit of force = Newton).

Example

A force of 1N acting on a mass of 1kg results in an acceleration of $1ms^{-2}$.

SI BASE UNITS

Quantity	Unit Symbol	Unit Name
length	m	metre
mass	kg	kilogram
time	s	second
electric current	A	ampere
temperature	K	Kelvin
luminous intensity	cd	candela

Decimal Multiples and Sub-multiples

Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

DERIVED UNITS

Geometrical

Symbol	Quantity	Unit Symbol	Unit Name
l,s	length, distance	m	metre
A	area	m^2	square metre
V	volume	m^3	cubic metre
α, β, γ etc	plane angle	rad	radian
		°	degree
α, β, γ etc	solid angle		steradian

Time-related

Symbol	Quantity	Unit Symbol	Unit Name
t	time	s	second
τ	time constant	s	second
u,v	velocity	ms^{-1}	metre per second
a	acceleration	ms^{-2}	metre per second per second
ω	angular velocity	rad s^{-1}	radian per second
α	angular acceleration	rad s^{-2}	radian per second per second
f	frequency	Hz	hertz
n	rotational frequency	s^{-1}	(revolution) per second

Mechanical

Symbol	Quantity	Unit Symbol	Unit name
m	mass	kg	kilogram
F	force	N	Newton
G(W)	weight	N	Newton
J	moment of inertia	kgm^2	kilogram metre squared
M(T)	torque	kgm	kilogram metre
W(E)	work (energy)	J	Joule
P	power	W	Watt
p	pressure	Pa	Pascal
E	modulus of elasticity	Pa	Pascal
σ	stress	Pa	Pascal
ρ	density	kgm^{-3}	kilogram per cubic metre
δ	rate of flow	m^3s^{-1}	cubic metre per second
k, k_1, etc	any constant factor		

GENERAL CONVERSION TABLES

LENGTH		SI UNIT – metre m
To convert from:	To:	Multiply by:
Mile	m	1609.344
Nautical Mile	m	1853
km	m	10^{3}
cm	m	10^{-2}
mm	m	10^{-3}
yd	m	0.9144
ft	m	0.3048
in	m	2.54×10^{-2}
mil	m	2.54×10^{-5}

FORCE & WEIGHT		SI UNIT – Newton N
To convert from:	To:	Multiply by:
tonf (ton wt)	N	9964
lbf (lb wt)	N	4.448
poundal	N	0.1383
ozf (oz wt)	N	0.2780
kp	N	9.807
p	N	9.81×10^{-3}
kgf (kg wt)	N	9.807
gf (g wt)	N	9.81×10^{-3}
dyn	N	10^{-5}

AREA		SI UNIT – square metre m^2
To convert from:	To:	Multiply by:
Square Mile	m^2	2.59×10^{6}
Acre	m^2	4047
Hectare ha	m^2	10^{4}
km^2 (sq. km)	m^2	10^{6}
cm^2	m^2	10^{-4}
mm^2	m^2	10^{-6}
yd^2	m^2	0.8361
ft^2	m^2	9.29×10^{-2}
in^2	m^2	6.45×10^{-4}
mil^2	m^2	6.45×10^{-10}

PRESSURE & STRESS		SI UNIT – Pascal Pa
To convert from:	To:	Multiply by:
at (technical atmosphere)	Pa	9.81×10^{4}
in WG	Pa	248.9
mm WG	Pa	10.34
in HG	Pa	3385
mm HG (torr)	Pa	131.0
kp cm^{-2}	Pa	9.81×10^{4}
Nm^{-2}	Pa	1.0
bar	Pa	10^{5}
lbf ft^{-2}	Pa	47.88
lbf in^{-2}	Pa	5895
kgf m^{-2}	Pa	9.807
kgf cm^{-2}	Pa	9.81×10^{4}

VOLUME		SI UNIT – cubic metre m^3
To convert from:	To:	Multiply by:
yd^3	m^3	0.765
ft^3	m^3	2.83×10^{-2}
in^3	m^3	1.64×10^{-5}
dm^3	m^3	10^{-3}
litre	m^3	10^{-3}
gallon (Imperial)	m^3	4.55×10^{-3}
gallon (U.S.)	m^3	3.79×10^{-3}
pint (Imperial)	m^3	5.68×10^{-4}
pint (U.S.)	m^3	4.73×10^{-4}

VELOCITY (LINEAR)		SI UNIT – metre per second ms^{-1}
To convert from:	To:	Multiply by:
mph (mile per hour)	ms^{-1}	0.4470
ft min^{-1}	ms^{-1}	5.08×10^{-3}
ft s^{-1}	ms^{-1}	0.3048
km h^{-1}	ms^{-1}	0.2778
m min^{-1}	ms^{-1}	1.67×10^{-2}
knot	ms^{-1}	0.5145

MASS		SI UNIT – kilogram kg
To convert from:	To:	Multiply by:
ton (Imperial)	kg	1016
ton (U.S.)	kg	907.2
tonne (metric ton)	kg	10^{3}
slug	kg	14.59
lb	kg	0.4536
oz	kg	2.84×10^{-2}
g	kg	10^{-3}

VELOCITY (ANGULAR)		SI UNIT – radian per second rad s^{-1}
To convert from:	To:	Multiply by:
rpm (revolutions per minute)	rad s^{-1}	0.1037 ($2\pi/60$)
r s^{-1} (revolutions per second)	rad s^{-1}	6.283 (2π)
° s^{-1} (degrees per second)	rad s^{-1}	1.75×10^{-2} ($2\pi/360$)

TORQUE		SI UNIT – Newton metre Nm
To convert from:	To:	Multiply by:
lbf ft	Nm	1.356
lbf in	Nm	0.1129
ozf in	Nm	7.062 x 10^{-3}
kgf m	Nm	9.8067
kp m	Nm	9.8067

ENERGY (WORK)		SI UNIT – Joule J
To convert from:	To:	Multiply by:
Btu (British Thermal Unit)	J	1.055 x 10^{3}
therm (10^5 Btu)	J	1.055 x 10^{8}
cal	J	4.187
ft lbf (ft lb wt)	J	1.356
ft poundal	J	0.0421

POWER		SI UNIT – kilowatt kW
To convert from:	To:	Multiply by:
HP (horsepower)	kW	0.7457
ps (pferdstärke)	kW	0.7355
ch, CV (cheval vapeur)	kW	0.7355
Btu s^{-1}	kW	1.055
kcal s^{-1}	kW	4.1868
ft lbf s^{-1}	kW	1.36 x 10^{-3}

MOMENT OF INERTIA		SI UNIT – kilogram metre^2 kgm^2
To convert from:	To:	Multiply by:
kgf m^2 (GD^2)	kgm^2	0.25
lbf ft^2 (WK^2)	kgm^2	4.21 x 10^{-2}
kp m s^2	kgm^2	9.807
ft lbf s^2	kgm^2	1.356
lbf in^2	kgm^2	2.926 x 10^{-4}
ozf in^2	kgm^2	1.829 x 10^{-5}

TEMPERATURE		SI UNIT – Kelvin K
To convert from:	To:	Factor:
°C (degree Celsius/ Centigrade)	K	x 1
t°C	K	t + 273.15
°F (degree Fahrenheit)	K	x 0.5555
t°F	K	(t – 32) x 0.5555

FLOW		SI UNIT – cubic metre per second m^3s^{-1}
To convert from:	To:	Multiply by:
gallon per hour (imperial)	m^3s^{-1}	1.26 x 10^{-6}
gallon per hour (US)	m^3s^{-1}	1.05 x 10^{-6}
litre per minute	m^3s^{-1}	1.67 x 10^{-5}
litre per second	m^3s^{-1}	10^{-3}
cfm (cubic foot per minute)	m^3s^{-1}	4.72 x 10^{-4}
m^3h^{-1} (cubic metre per hour)	m^3s^{-1}	2.78 x 10^{-4}
m^3min^{-1} (cubic metre per minute)	m^3s^{-1}	1.67 x 10^{-2}

CHAPTER 2 CONVERSION TABLES — SERVO

The main conversion factors used in motion control are summarised in the following tables

TORQUE		SI UNIT – Newton metre Nm
To convert from:	To:	Multiply by:
lb ft	Nm	1.356
lb in	Nm	0.1129
oz in	Nm	7.062 x 10^{-3}
Nm	lb ft	0.7375
Nm	lb in	8.857
Nm	oz in	141.6

MOMENT OF INERTIA		SI UNIT – kilogram metre^2 kg m^2
To convert from:	To:	Multiply by:
lb in s^2	kg m^2	0.113
oz in s^2	kg m^2	7.06155 x 10^{-3}
kg m^2	lb in s^2	8.85075
kg m^2	oz in s^2	141.612
kg cm^2	kg m^2	10^{-4}

FORCE		SI UNIT – Newton N
To convert from:	To:	Factor:
lb(f)	N	4.4482
N	lb(f)	0.22481

LINEAR ACCELERATION		SI UNIT – metres per second^2 ms^2
To convert from:	To:	Multiply by:
in s^{-2}	ms^{-2}	2.54 x 10^{-2}
ft s^{-2}	ms^{-2}	0.3048
ms^{-2}	in s^{-2}	39.37
ms^{-2}	ft s^{-2}	3.2808

TABLE AX3

PROPERTIES OF ROUND COPPER CONDUCTORS

Gauge number AWG/ B & S	Diameter of bare conductor		Cross section		Resistance mΩ/m or Ω/km		Weight g/m or kg/km	Typical diameter of insulated magnet wire used in relays, magnets, motors, trans-formers, etc.
	mm	mils	mm^2	cmils	25°C	105°C		mm
250MCM	12.7	500	126.6	250 000	0.138	0.181	1126	
4/0	11.7	460	107.4	212 000	0.164	0.214	953	
2/0	9.27	365	67.4	133 000	0.261	0.341	600	
1/0	8.26	325	53.5	105 600	0.328	0.429	475	
1	7.35	289	42.4	87 700	0.415	0.542	377	
2	6.54	258	33.6	66 400	0.522	0.683	300	
3	5.83	229	26.6	52 600	0.659	0.862	237	
4	5.18	204	21.1	41 600	0.833	1.09	187	
5	4.62	182	16.8	33 120	1.05	1.37	149	
6	4.11	162	13.30	26 240	1.32	1.73	118	
7	3.66	144	10.5	20 740	1.67	2.19	93.4	
8	3.25	128	8.30	16 380	2.12	2.90	73.8	
9	2.89	114	6.59	13 000	2.67	3.48	58.6	3.00
10	2.59	102	5.27	10 400	3.35	4.36	46.9	2.68
11	2.30	90.7	4.17	8 230	4.23	5.54	37.1	2.39
12	2.05	80.8	3.31	6 530	5.31	6.95	29.5	2.14
13	1.83	72.0	2.63	5 180	6.69	8.76	25.4	1.91
14	1.63	64.1	2.08	4 110	8.43	11.0	18.5	1.71
15	1.45	57.1	1.65	3 260	10.6	13.9	14.7	1.53
16	1.29	50.8	1.31	2 580	13.4	17.6	11.6	1.37
17	1.15	45.3	1.04	2 060	16.9	22.1	9.24	1.22
18	1.02	40.3	0.821	1 620	21.4	27.9	7.31	1.10
19	0.91	35.9	0.654	1 290	26.9	35.1	5.80	0.98
20	0.81	32.0	0.517	1 020	33.8	44.3	4.61	0.88
21	0.72	28.5	0.411	812	42.6	55.8	3.66	0.79
22	0.64	25.3	0.324	640	54.1	70.9	2.89	0.70
23	0.57	22.6	0.259	511	67.9	88.9	2.31	0.63
24	0.51	20.1	0.205	404	86.0	112	1.81	0.57
25	0.45	17.9	0.162	320	108	142	1.44	0.51
26	0.40	15.9	0.128	253	137	179	1.14	0.46
27	0.36	14.2	0.102	202	172	225	0.908	0.41
28	0.32	12.6	0.080	159	218	286	0.716	0.37
29	0.29	11.3	0.065	128	272	354	0.576	0.33
30	0.25	10.0	0.0507	100	348	456	0.451	0.29
31	0.23	8.9	0.0401	79.2	440	574	0.357	0.27
32	0.20	8.0	0.0324	64.0	541	709	0.289	0.24
33	0.18	7.1	0.0255	50.4	689	902	0.228	0.21
34	0.16	6.3	0.0201	39.7	873	1140	0.179	0.19
35	0.14	5.6	0.0159	31.4	1110	1450	0.141	0.17
36	0.13	5.0	0.0127	25.0	1390	1810	0.113	0.15
37	0.11	4.5	0.0103	20.3	1710	2230	0.091	0.14
38	0.10	4.0	0.0081	16.0	2170	2840	0.072	0.12
39	0.09	3.5	0.0062	12.3	2820	3690	0.055	0.11
40	0.08	3.1	0.0049	9.6	3610	4720	0.043	0.1

ABBREVIATIONS FOR MULTIPLES AND SUB-MULTIPLES

M . .	mega or meg	10^6
k . .	kilo	10^3
c . .	centi	10^{-2}
m . .	milli	10^{-3}
μ .	micro	10^{-6}
$\mu\mu$ or p .	micromicro or pico	10^{-12}

GREEK LETTERS USED AS SYMBOLS IN THIS BOOK

Letter	Capital	Small
Alpha .	—	α (angle, temperature coefficient of resistance)
Delta . .	Δ (increment, mesh connection)	δ (small increment)
Epsilon .	—	ϵ (permittivity)
Eta . .	—	η (efficiency)
Theta .	—	θ (angle, temperature)
Lambda .	—	λ (wavelength)
Mu . .	—	μ (micro, permeability, amplification factor)
Pi . .	—	π (circumference/diameter)
Rho . .	—	ρ (resistivity)
Sigma .	Σ (sum of)	σ (conductivity)
Phi . .	Φ (magnetic flux)	ϕ (angle, phase difference)
Psi . .	Ψ (electric flux)	—
Omega .	Ω (ohm)	ω (solid angle, angular velocity, angular frequency)

MISCELLANEOUS

Term	Symbol	Term	Symbol
Approximately equal to	$\simeq$	Base of natural logarithms . .	ϵ
Proportional to . .	$\propto$	Common logarithm of x	$\log x$
Infinity . . .	∞	Natural logarithm of x	$\ln x$
Sum of . . .	Σ	Complex operator $\sqrt{-1}$ . . .	j
Increment or finite difference operator .	Δ, δ	Temperature . .	θ
Greater than . .	$>$	Time constant . .	T
Less than . . .	$<$	Efficiency . .	η
Much greater than .	$\gg$	Per unit . . .	p.u.
Much less than . .	$\ll$		

<u>*Definition of a Transducer*</u>

A transducer is a device that receives energy from one source and retransmits it, often in a different form, to another system.

Introduction to Transducers for Instruments

Gould

<u>*TRANSDUCER TYPES commonly used*</u>

Transducer	*Input / Output*
Opto-coupler	Light/ Electric
LDR *light dependant resistor*	/
LED *Light emitting diode*	/
Photo-transistor	/
Torch battery	/
Thermistor	/
Thermocouple *Seebeck effect*	/
Peltier effect device	/
RTD *Resistance Temperature detector*	/
Piezo electric device	/
Speaker	/
Magnetic Pick-up	/
Microphone	/
Hall Effect Devices	/
Strain gauge Load cell	/
Speed Detector	/

UNITS OF MEASUREMENT

ITEM	UNIT	UNIT ABBREVIATION
MASS	KILOGRAM	kg
TIME		
VELOCITY		
ACCELERATION		
LENGTH DISPLACEMENT		
TEMPERATURE (absolute)		
TEMPERATURE (common scale)		
FORCE		
SOUND		
LIGHT INTENSITY		
LUMINOUS FLUX		
ILLUMINATION		
MAGNETIC FLUX		
MAGNETIC FLUX DENSITY		
PRESSURE		

TABLE 1.1
Base Units of the International System

Quantity	Name of unit	Unit symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol

The most common physical measurands and relevant units given in the SI system are listed on the following pages.

Linear and Angular Position, Motion, Length, and Thickness: Linear displacement is measured in meters (m) or in multiples and submultiples of the meter, which are the kilometer (km), centimeter (cm), millimeter (mm), and micrometer (μm, called also *micron*). An angular displacement is measured in radians (rad) or degrees (°). One radian is equal to 57.3 degrees. The minute of an arc, or *arc-minute,* is equal to 1/60 of 1°. The second of an arc, or *arc-second,* is equal to 1/3600 of 1°.

Linear and Angular Velocity: Linear velocity is measured in meters per second (m/s) or in multiples and submultiples: km/s and cm/s. A commonly used speed is kilometers per hour (km/h). Angular speed is measured in radians per second (rad/s). Submultiples are the milliradian per second (mrad/s) and microradian per second (μrad/s). Non-SI but frequently used units are the degree per second (°/s) and revolutions per minute (r/min.). One revolution is equal to 2π radians or to 360°.

Acceleration and Jerk: Linear acceleration is measured in meters per second squared (m/s^2). Angular acceleration is measured in radians per second squared (rad/s^2). Quite commonly, linear acceleration is expressed in *g*'s, where *g* is a symbol of acceleration caused by the force of the earth's gravity. $1g = 9.80665\ m/s^2$. The symbol *g* should not be confused with the similar symbol used for the gram (italic script is utilized for denoting acceleration).

Attitude and Attitude Rate: Attitude is the position or orientation in motion or at rest of an aircraft, spacecraft, or other body. Attitude is determined by the relationship between axes of the body and some reference line, plane, fixed system, or reference axes.

Attitude is expressed in radians (rad) and in degrees (°), or in their submultiples: milliradians (mrad), minutes (′), and seconds (″).

The attitude rate is measured in radians per second (rad/s) or in submultiples: milliradians per second (mrad/s).

Attitude-sensing instruments provide measurements with respect to a predetermined reference system. One typical system is three mutually orthogonal axes.

Stress and Strain: The deformation of solids is evaluated by measuring stress. Several mechanical parameters can be calculated using the values found for stress. Among these parameters are shear stress, Poisson's ratio, modulus of elasticity (Young's modulus), elastic limit, torsional deflection, and other parameters.

Strain is measured as a dimensionless ratio of the same length unit (m/m) which is sometimes called *strain.* It is also expressed in submultiples of strain, for instance *microstrains* ($\mu\varepsilon$), $1\mu\varepsilon = 1 \times 10^{-6}$ m/m. The unit for the modulus of elasticity and stress is newtons per square meter (N/m^2).

Force and Mass (or weight): Weight is the force of attraction of the body toward the earth. The mass of a body can be calculated by dividing weight by the acceleration due to gravity. The unit of force is the newton (N). In terms of basic SI units, N is equivalent to $kg \cdot m/s^2$. The unit of mass is the kilogram (kg).

Torque: Torque is measured in newton-meters ($N \cdot m$).

Pressure: Pressure is measured in units of force per unit of area, i.e., N/m^2. This unit is called the pascal (Pa). The pascal is a very small unit and the use of decimal multiples of the Pa is typical for practical measurements. Among these multiples are the hectopascal (hPa, 1hPa = 100Pa), the kilopascal (kPa, 1kPa = 1000Pa), and the megapascal (MPa, 1MPa = 1×10^6Pa).

Acoustic Pressure: Sound is measured in terms of the pressure (Pa) or power (W) which it develops. However, the most commonly used unit in practice for evaluating the sound pressure level is the decibel, which is 20 times the logarithm to the base 10 of the ratio of the effective values of the measuring and reference sound pressure levels. Unless a different reference pressure is specified, a pressure of 20μPa (2×10^{-4} μbar) is usually taken as the reference. Another unit used in acoustic engineering is the acoustic ohm, which is the ratio of the acoustic pressure to the flow rate ($N \cdot s/m^5$).

Flow Rate: Flow rate can be expressed in terms of mass flow rate (kg/s) or volumetric flow rate (m^3/s).

Level of Liquid: The level of a liquid or other substance is measured as the height of its surface above a reference point. Quite often the measured height is used for calculating the volume or mass of a liquid if the dimensions of the tank and the density of the liquid are known. The direct unit for the measurement of level is the meter (m).

Humidity, Moisture, and Dew Point: Humidity is a measure of the water content in a gas. Moisture is a general term relating to water content in gases, liquids, and solids.

Relative humidity is measured in percent (%RH). Absolute humidity is expressed in units of mass per unit volume (kg/m^3 and also g/m^3). Moisture is given in percent by volume or by weight.

Vacuum: It is assumed in practical engineering that a vacuum is a space in which the pressure is far below the normal atmospheric pressure, typically lower than 7kPa.

Traditionally, a vacuum is measured in torrs (1torr = 1mmHg = 133.32Pa). The range of measurement is extended from 760torr (low vacuum) to 1×10^{-9} torr (ultra-high vacuum).

Density and Specific Gravity of a Substance: Density and specific gravity are the mass and weight of a given substance per unit volume, respectively. The corresponding units are kg/m^3 and N/m^3.

Viscosity of Fluid: Viscosity is a fluid's resistance to flow. Absolute (dynamic) viscosity is expressed in $N \cdot s/m^2$. Kinematic viscosity is the absolute viscosity divided by the fluid's density. The units for kinematic viscosity are m^2/s. Relative viscosity is the ratio of absolute viscosity to the viscosity of a liquid, which is taken as a reference (quite commonly the liquid is water). Relative viscosity is dimensionless.

Temperature: The SI unit of temperature is the kelvin (K). Absolute zero is 0K. On the kelvin scale, the ice and steam points are 273.15K and 373.15K, respectively. On the Celsius scale, the ice and steam points are defined at 0°C and 100°C, respectively. The Celsius scale is widely used in measurements. Note that 1°C = 1K.

The following relationship can be used for the conversion of Fahrenheit (°F) and Celsius (°C) scales: °F = (9/5) × °C + 32.

Heat Radiation Intensity and Heat Flux: Radiation intensity is measured in units of power per unit of area, W/m^2 or W/cm^2.

A heated object radiates electromagnetic waves in the ultraviolet, visible, and infrared regions of the electromagnetic spectrum. The energy radiated by the object is proportional to its temperature. Typically, the outputs of the instruments are given in units of temperature: degrees Celsius (°C), degrees Fahrenheit (°F), or kelvin (K). The length of radiated waves is expressed in micrometers.

Heat flux is expressed in watts (W) or in watts per square meter (W/m^2). Quite often, measurements of heat flux are associated with the quantitative evaluation of the heat energy received from the sun. The measure of this energy is the solar constant which is the power per square meter received from the sun. One solar constant is equal to $1353 W/m^2$.

Light Intensity: Light intensity is measured for the lengths of waves between 10nm and 1mm. The lengths of waves in the light spectrum lie between 10nm and 1mm. The rage for visible light is from 380 to 780nm, for ultraviolet (UV) radiation from 10 to 380nm, and for infrared (IR) radiation from 780 to 1×10^6nm (the portion between 780nm and 3μm is called near IR, and the portion between 3μm and 1000μm is called far IR).

Several units are used most often in optical measurements. Luminous intensity is measured in candelas (cd). The candela is one of the basic SI units. Luminous flux is expressed in lumens (lm). The unit of illuminance is the lux (lx). One lux is equal to one lumen per square meter. Brightness or luminance is expressed in candelas per square meter of light-emitting area (cd/m^2). Wavelengths of UV and visible light are usually given in nanometers (nm) and, for IR light, in micrometers (μm). Non-visual magnitudes are radiant flux (watts, W), radiant intensity (watts per steradian, W/sr, or watts per square meter, W/m^2), and radiance [watts per square meter per steradian, $W/(m^2 \cdot sr)$].

Voltage, Electrostatic Charge, Current, Electrical Power, Elapsed Time, and Frequency: The units corresponding to these quantities are the volt (V) for voltage, the coulomb (C) for electrostatic charge, the ampere (A) for current, the watt (W) for electrical power, the second (s) for elapsed time, and the hertz (Hz) for frequency.

Magnetic Field Intensity and Flux Density: The SI units for field intensity and flux density are the ampere per meter (A/m) and the tesla (T), respectively.

Radioactivity: The SI unit for radioactivity is the becquerel (Bq). It is the activity of a radionuclide decaying when its rate is one spontaneous transition per second.

Another quantity that is frequently used for measuring radiation is exposure dose. It is expressed in coulombs per kilogram (C/kg) and represents the exposure when nuclear radiation produces in air one coulomb of electrical charge per kilogram of dry air.

Chemical Properties and Chemical Composition: Almost all physical quantities are intermediate agents for chemical measurands; the relevant units are quite diversified.

TABLE 1.2
Principles of Transduction

No.	The change in the . . .	is caused by the change in the . . .
1	2	3
1	Resistance of a resistive element	a. Position of a wiper in a linear or angular potentiometer. b. Resistivity and dimensions of a strain-gage material that undergoes strain. c. Geometry of an elastic pipe carrying conductive liquid. d. Resistivity of a temperature-sensitive metallic or semiconductor material that experiences heating or cooling. e. Position of plates in a vacuum tube (change in transconductance). f. Voltage across or current in a varistor (an element having nonlinear volt-ampere characteristics). g. Resistivity of a metallic or semiconductor material sensitive to the strength of the magnetic field. h. Resistivity of a semiconductor material as a response to the incident light intensity. i. Concentration of chemicals in a solution.
2	Self-inductance or mutual inductance of an inductive element	a. Length of the magnetic path. b. Cross-sectional area of the magnetic path. c. Permeability of the ferromagnetic material in the magnetic path due to the stress developed in the material; changes in its chemical composition or temperature. d. Inductive coupling between two or more coils, which is caused by the variation of the distance between the coils, their mutual orientation, inducement of eddy currents, and magnetic properties of the magnetic path under stressing or heating.
3	Capacitance of a capacitive element	a. Distance between two electrodes, which constitute a capacitor. b. Congruous area between two electrodes, which constitute a capacitor. c. Dielectric constant due to the displacement of a high-dielectric-constant-material spacer between the capacitor's electrodes; stress or heat applied to a stress- or temperature-sensitive spacer; variation of the chemical properties of a substance between the electrodes.
4	Electrical charges	Process of ionization of gases exposed to radiation from radioactive sources.
5	Voltage or current developed by a self-generating element	a. Relative position of a conductor and the lines of a magnetic field when they have a relative speed and the conductor crosses the lines. b. Temperature of two junctions when each of them contains two contacting conductors of different metals (Seebeck Effect in thermocouples). c. Electric charges developed in a crystal that undergoes heating (Pyroelectric Effect). d. Electric charges induced in a crystalline or ceramic material experiencing stress (Piezoelectric Effect). e. Radiant energy of light incident upon the p-n junction in a semiconductor (Photovoltaic Effect). f. Production of electrical energy during chemical action. g. Development of an opposite electrical charge in two dissimilar uncharged, contacting metals (Contact-Potential Effect). h. Motion of a liquid passing through a stationary capillary tube or porous body when the electric potential gradient is developed along the tube or pore (Electrokinetic Effect).
6	Voltage or current developed in an element fed from an ancillary source of energy	a. Transverse electric potential gradient in a current-carrying metal or semiconductor when a magnetic field is applied at right angles to the direction of current (Hall Effect). b. Electric potential gradient along a strip of metal carrying heat flow when the strip is exposed to a magnetic field perpendicular to its plane (Nernst Effect). c. Resistance and capacitance in a conductor, due to the field produced by an adjacent conductor (Proximity Effect). d. Velocity of discharged electrons liberated from a surface subjected to light providing a photoemissive current through the electrodes in a vacuum tube when a high voltage is applied between the electrodes (Photoemissive Effect).
7	Optical properties of a transparent material	Double refraction when the material is subjected to stress (Photoelastic Effect).
8	Emission of light	a. Heating of certain substances (e.g., diamond) below the red-hot temperature. b. Chemical action. c. Excitation by fast electron bombardment. d. Excitation by strong electric field. e. Excitation of phosphors by electromagnetic radiation of waves having various spectrums of lengths. f. Excitation of phosphors by radioactive particles.
9	Size or position of a body	a. Extension or contraction of the body as a function of temperature. b. Forces of acceleration. c. Pressure of heated or cooled gas confined in a sealed container. d. Pressure acting upon a diaphragm, bellows, Bourdon tube, or other pressure-sensitive element. e. Angular momentum (in a gyroscope).

TABLE 1.3
Transducer Design Characteristics

Measurand	*Electrical*	*Mechanical*
Range	Excitation	Configuration
Overrange	Isolation	Dimensions
Recovery time	Grounding	Mountings
	Source impedance	Connections
	Load impedance	Case material
	Input impedance	Materials in contact with measured fluids
	Output impedance	Case sealing
	Insulation resistance	Identification
	Breakdown voltage rating	
	Gain instability	
	Output	
	End points	
	Ripple	
	Harmonic content	
	Noise	
	Loading error	

TABLE 1.4
Transducer Performance Characteristics

Static	*Dynamic*	*Environmental*
1	2	3
Resolution	Frequency response	Operating environmental effects
Threshold	Transient response:	operating temperature range
Creep	response time	thermal zero shift
Hysteresis	rise time	thermal sensitivity shift
Friction error	time constant	—or—
Repeatability	Natural frequency	temperature error
Linearity	Damping	—or—
(+reference line)	Damping ratio	temperature error band
Sensitivity	Overshoot	temperature gradient error
Zero-measured output	Ringing frequency	acceleration error
Sensitivity shift		—or—
Zero shift		acceleration error band
Conformance		attitude error
(+reference curve)		vibration error
—or—		—or—
Static error band		vibration error band
(+reference line or curve)		ambient-pressure error
Reference lines:		—or—
theoretical slope		ambient-pressure error band
terminal line		mounting error
end-point line		Nonoperating environmental effects
best straight line		Type-limited environmental effects
least-squares line		conduction error
Reference curves:		strain error
theoretical curve		transverse sensitivity
mean-output curve		reference-pressure error

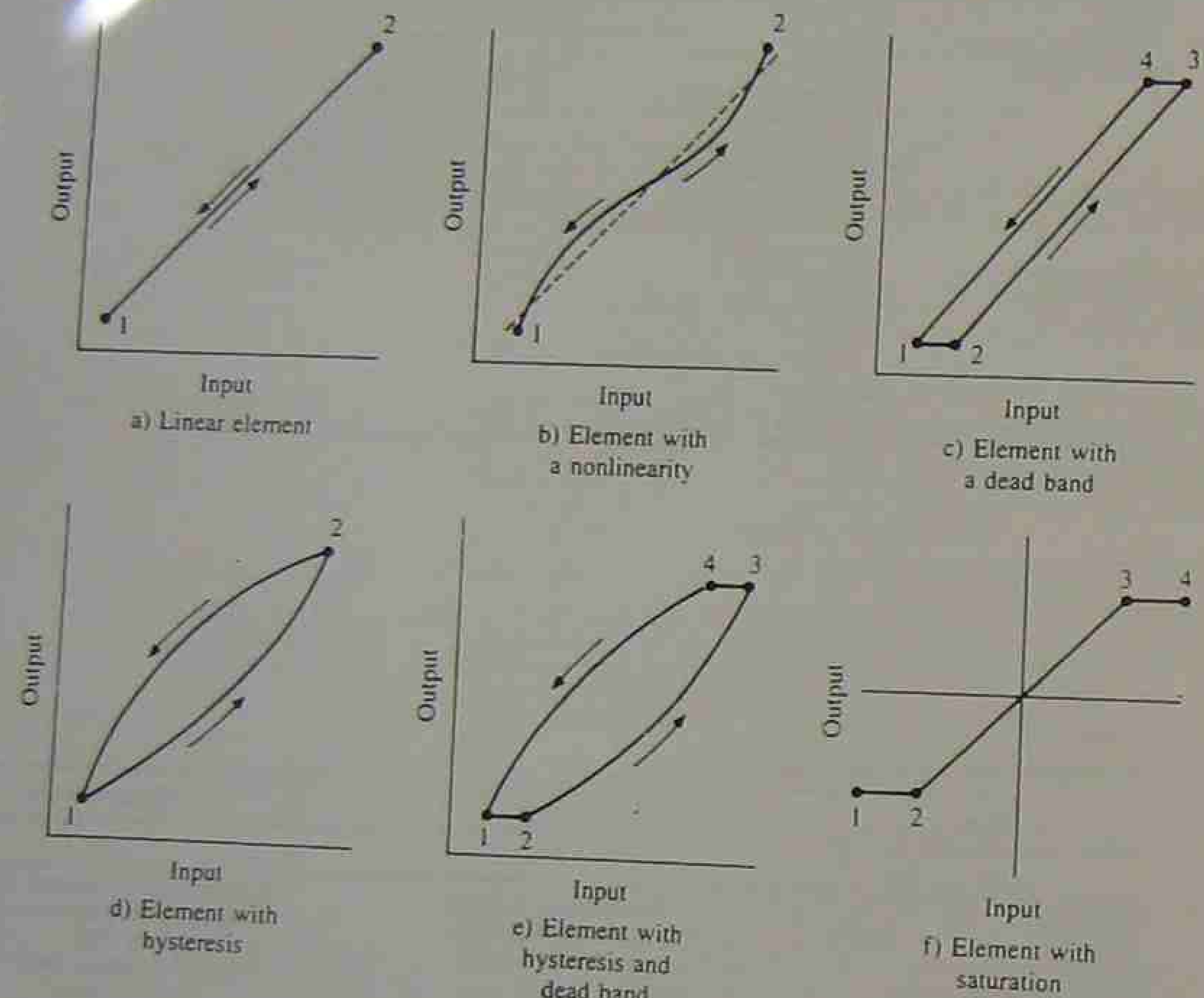

Figure 1.11 Input/output graphs of various nonlinear elements.

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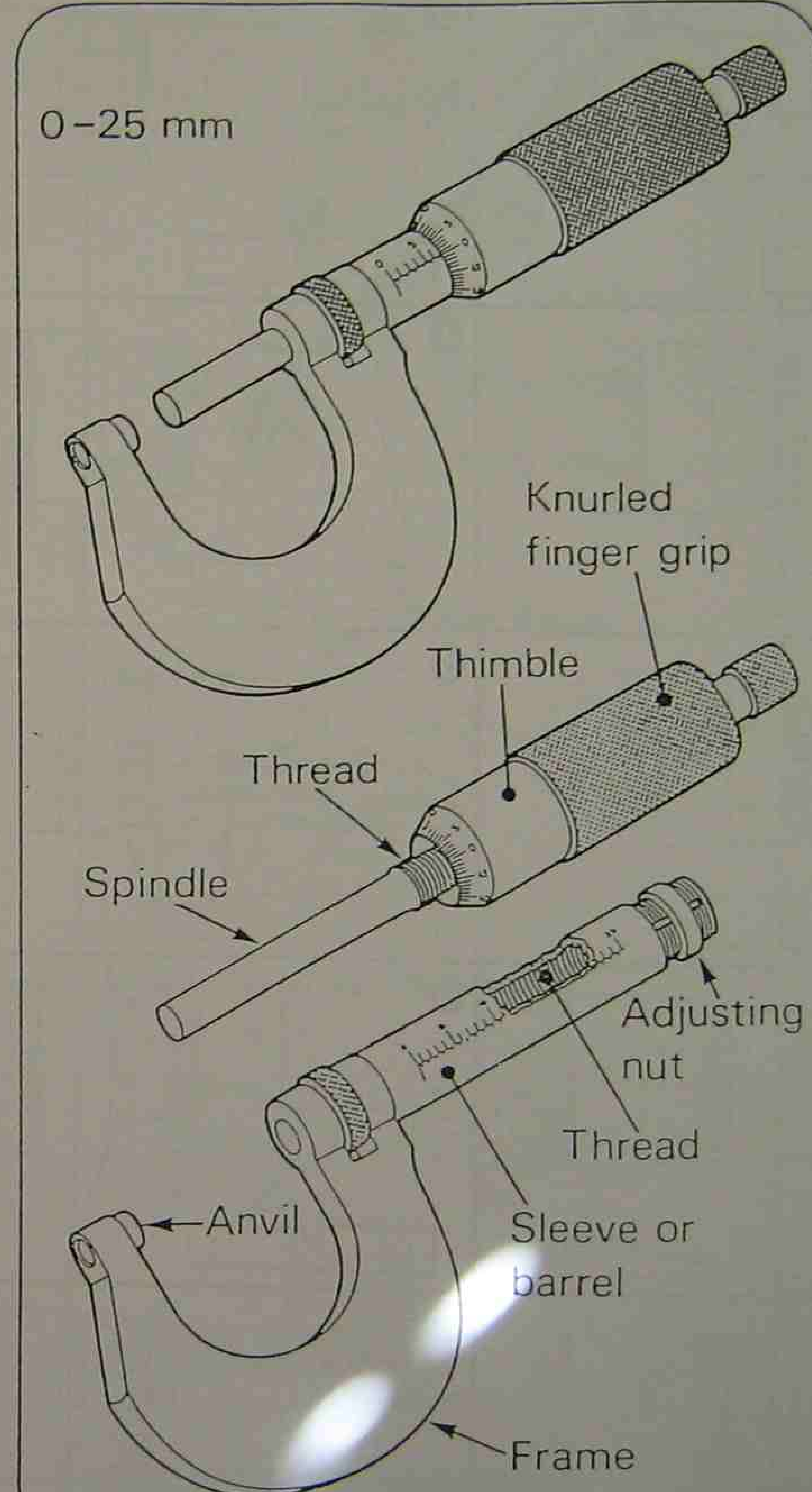
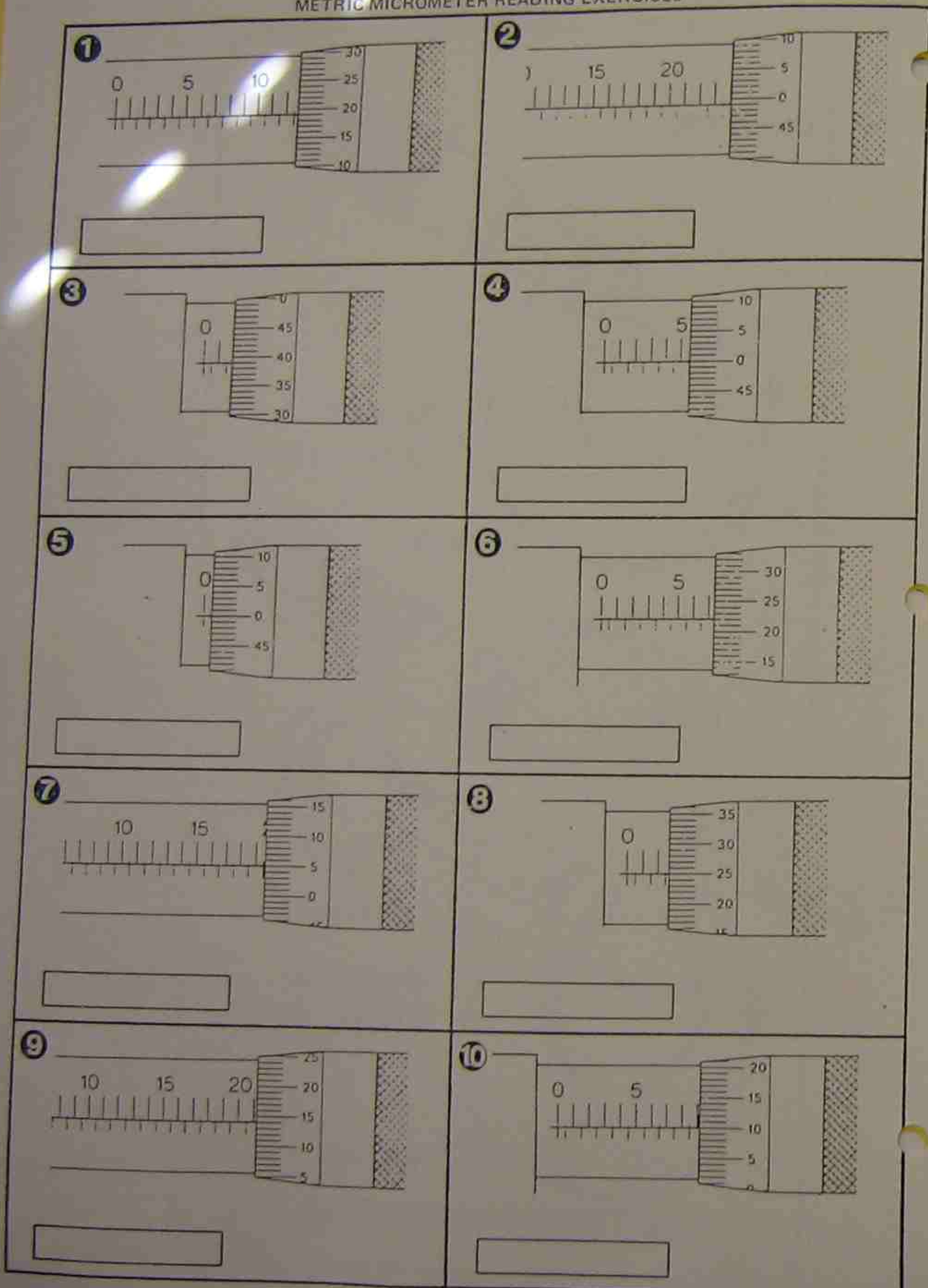
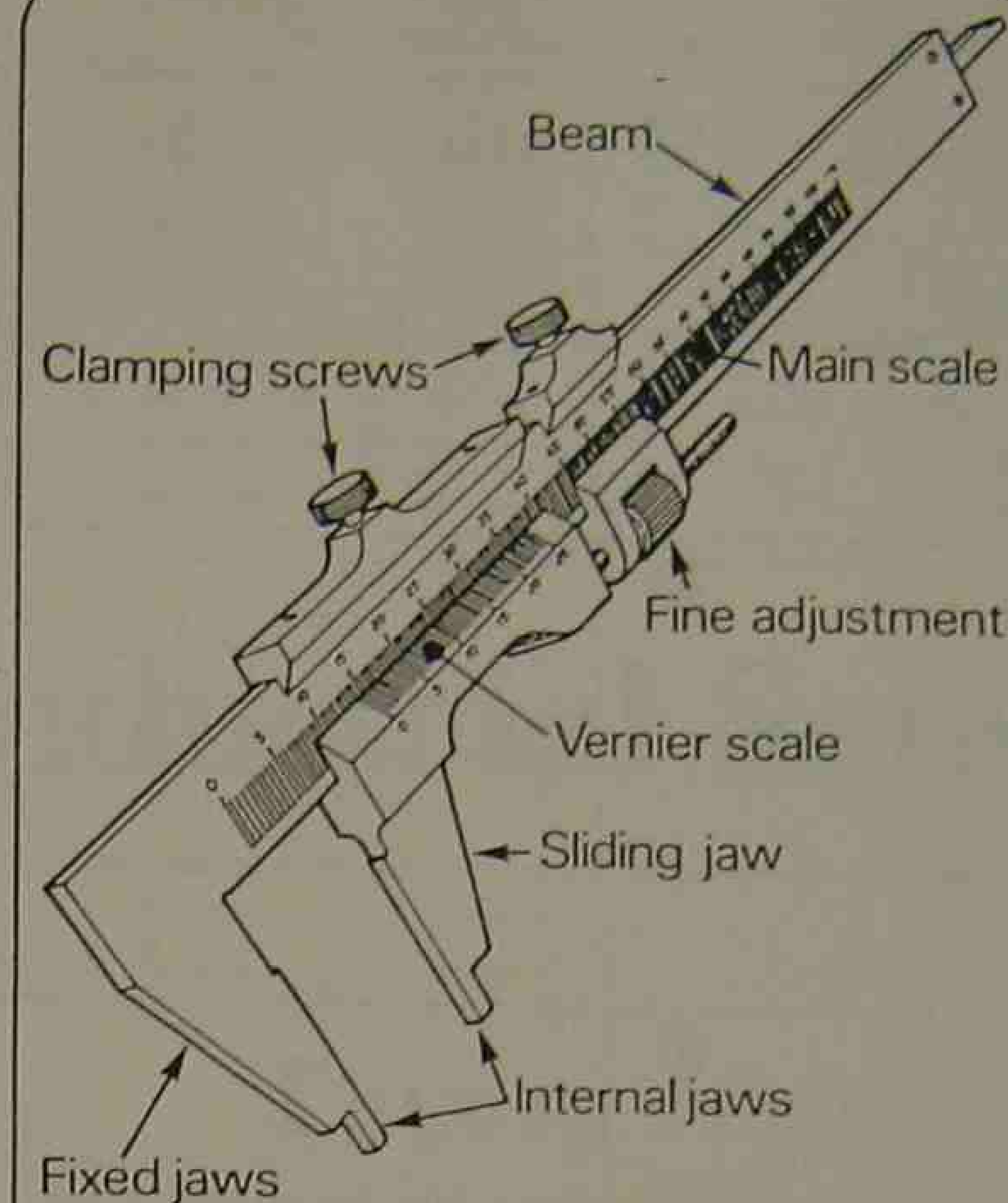
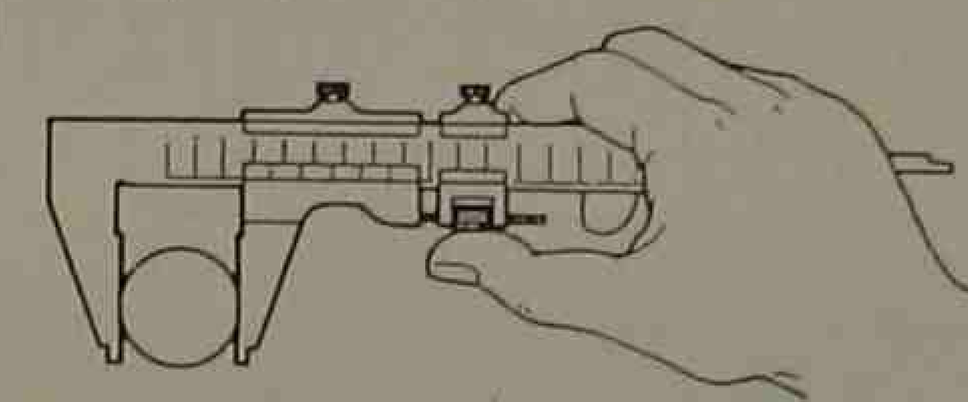


OUTSIDE MICROMETER

METRIC MICROMETER READING EXERCISES

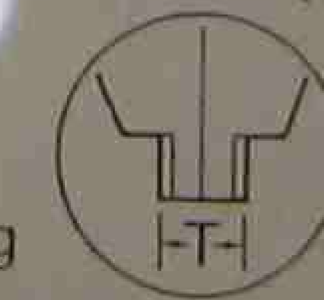






Measuring an outside diameter

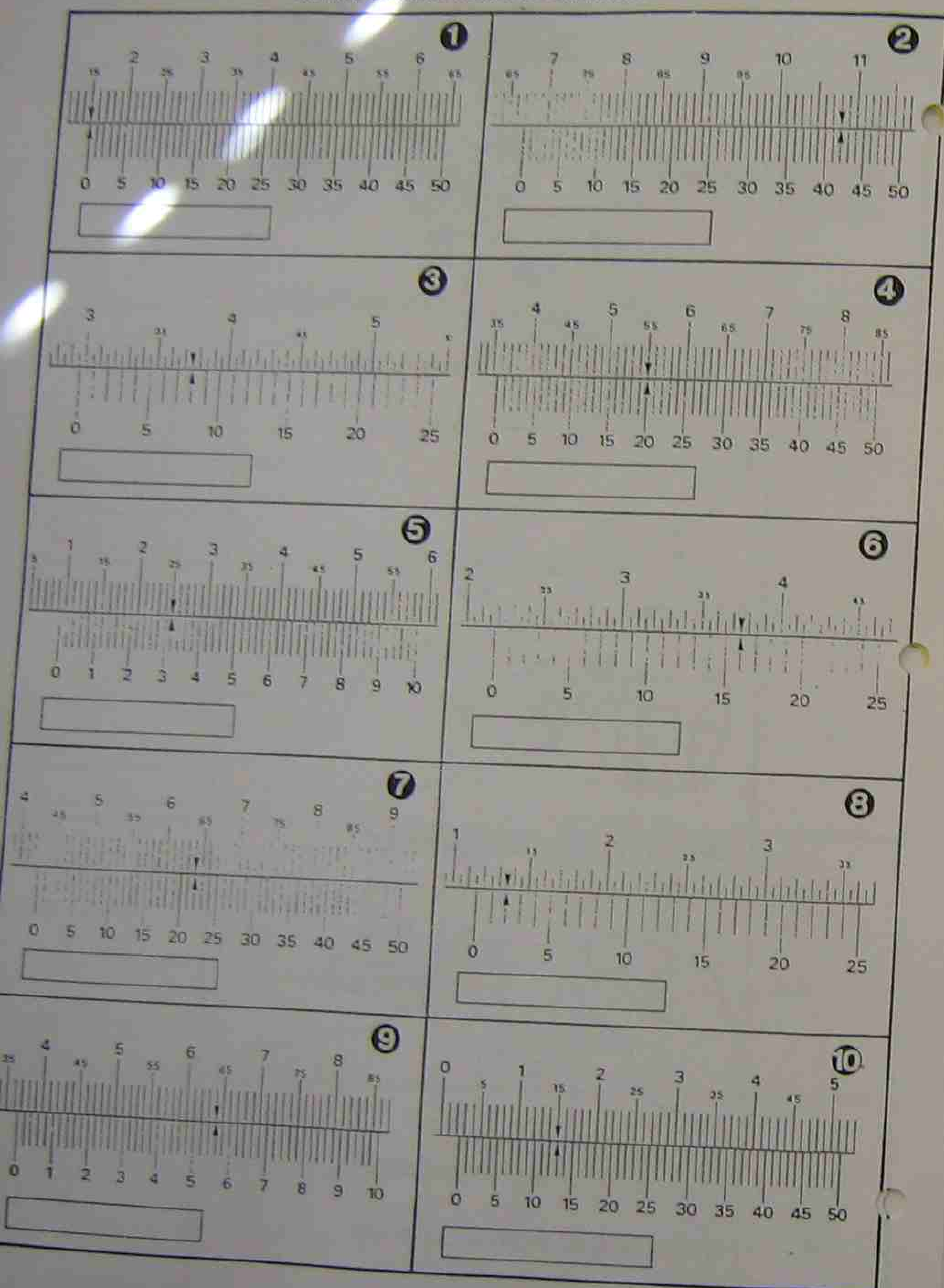
Jaw thickness added to Vernier reading



Measuring an internal diameter

VERNIER CALIPERS

METRIC VERNIER READING EXERCISES



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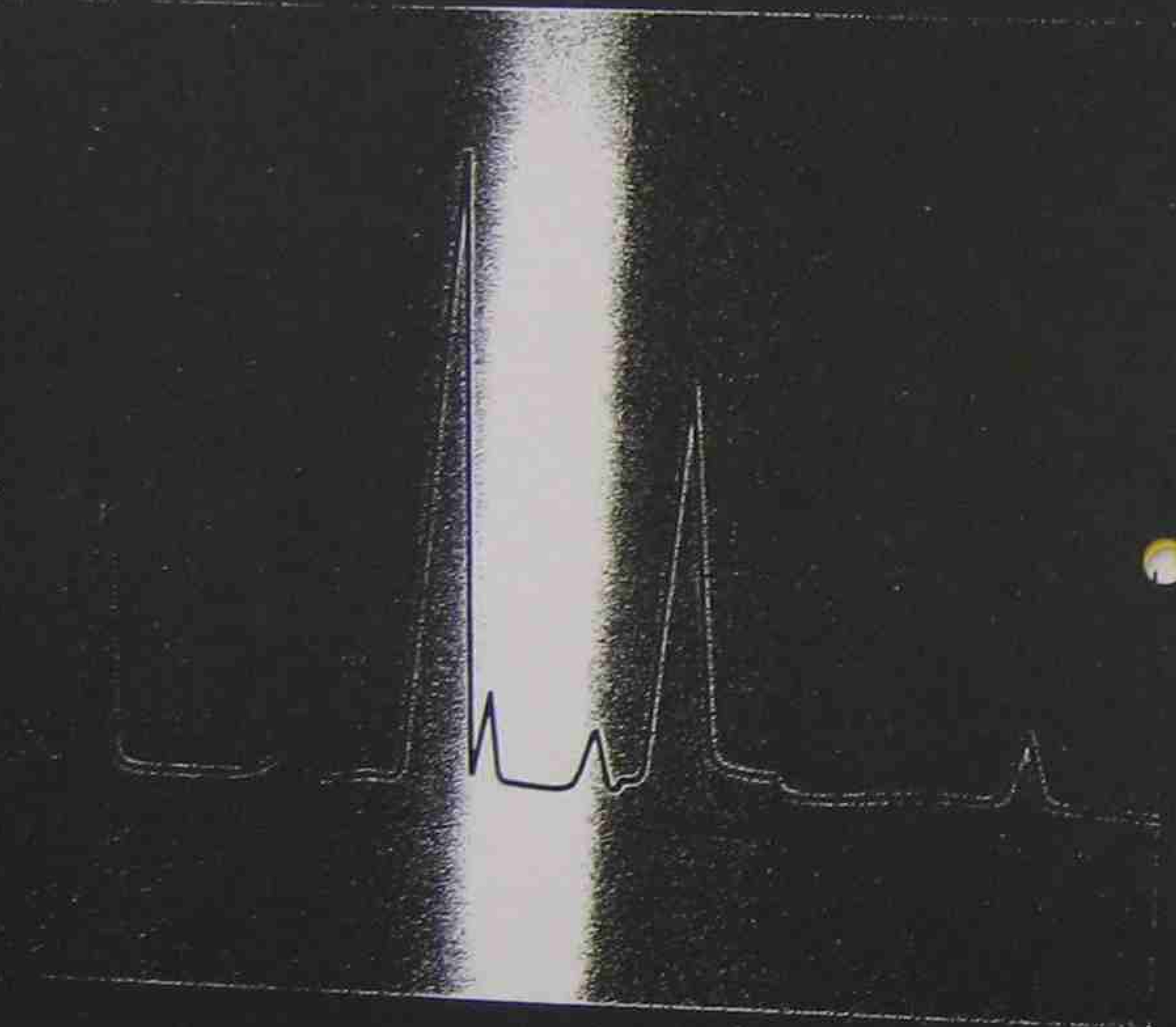
LIGHT



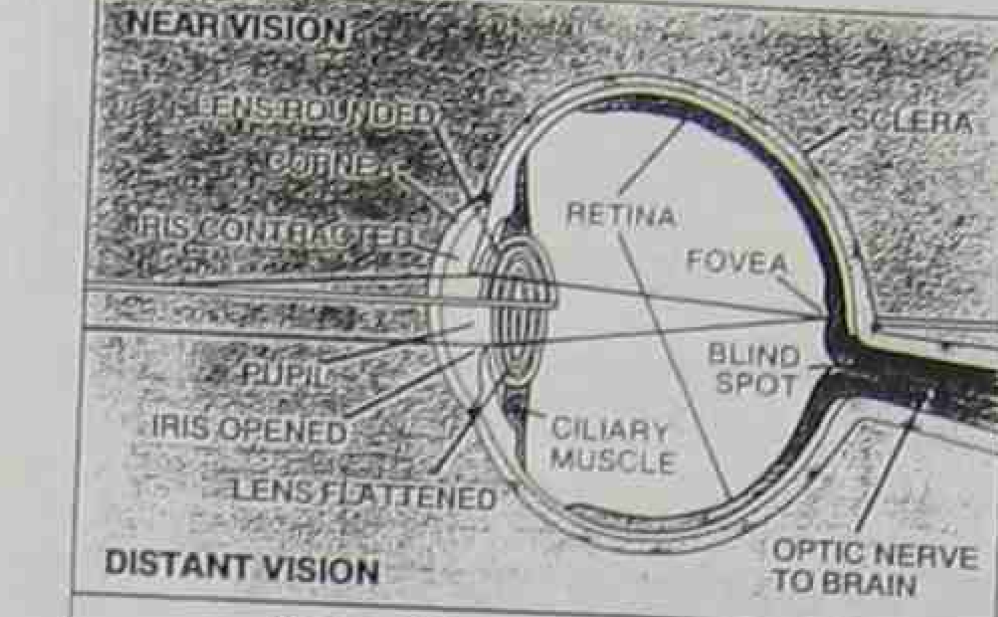
Sight · Science · Sources

PHILIPS

The Eye and how we see

Without the eye, light would have no meaning. Sight gives us the most detailed information about our surroundings. We depend on the eye forming images on nerve cells which are stimulated into sending signals along the optic nerve to the visual centres of the brain.

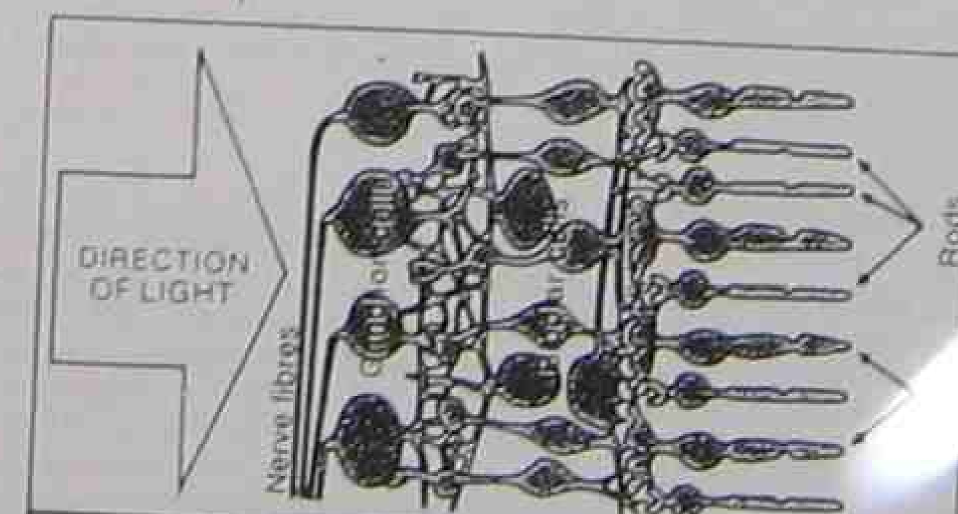
Our eyes are roughly spherical and 25 mm in diameter. They can swivel in any direction and six positioning muscles ensure that the visual axes of both eyes converge no matter where we look.



Sectional diagram of human eye

The tough outer layer of the eye, the sclera or "white", has a transparent area, called the cornea, through which light enters. The amount of light entering is controlled by the iris, a coloured diaphragm (the "colour" of your eyes). The hole in the diaphragm (called the pupil) can vary in size from 2 to 8 mm in diameter. As the brightness of the field of view increases, the pupil size decreases. When we are in the dark, our pupils enlarge to their maximum size.

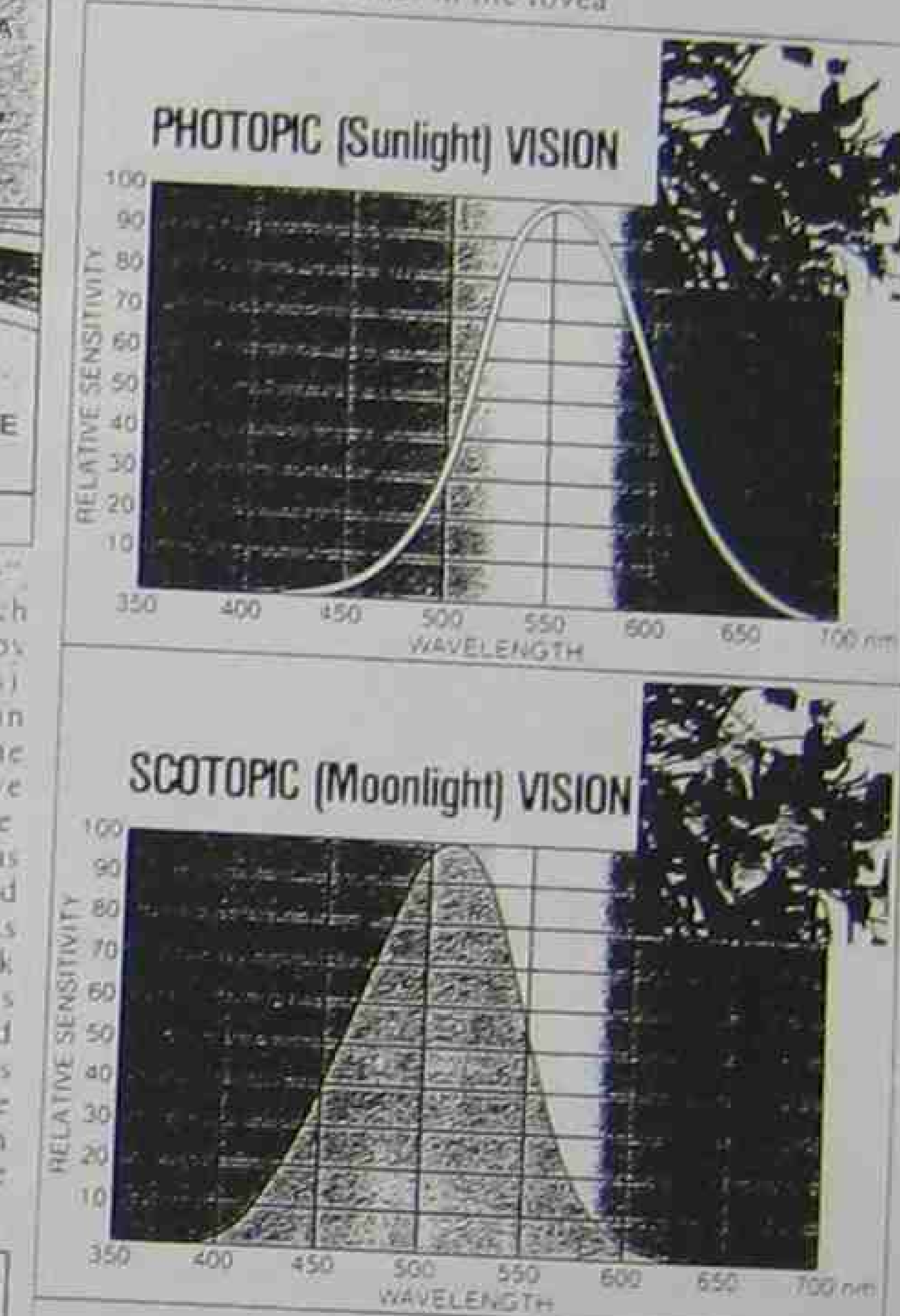
The lens, which focuses images onto the retina, is behind the iris. It is made like an onion in many layers, and is capable of changing its shape. Radial ligaments normally keep the lens fairly flat. However when we look at close objects, the ligaments contract to make the lens more rounded. This process of changing focus is called accommodation. The retina is the start of the nervous system leading to the brain and covers almost ⅔ of the inner surface of the eye. Each retina has about 100 million light sensitive nerve endings called rods and cones because of their shape.



Cross section through retina

There are nearly ten times as many rods as cones. Rods are spread fairly evenly over the retina; cones are concentrated on the visual axis in an area called the fovea. Rods are very sensitive to light but cannot distinguish colour. Cones are less sensitive but can distinguish colours. Because they are closely packed and have individual nerve connections, the cones enable us to see very fine detail.

We therefore have two kinds of vision – one depending on cones, the other on rods. As the light level changes so our eyes are constantly adapting to suit. The full range of sensitivity of the eye is greater than ten billion to one. In bright light, the cones provide photopic vision with high definition and colour discrimination using the area of the retina in the fovea. In moonlight however, the rods give us scotopic vision which is in shades of grey with less resolution of detail. So if you want to see very weak lights don't look straight at them. The image will then fall on the rods and not the cones in the fovea.



Relative spectral sensitivity of human eye

The change from scotopic to photopic vision is gradual and takes place between one hundredth and ten candela/m². Vision in this region relies on both rods and cones and is called mesopic vision.

Light is turned into nerve signals by a pigment called rhodopsin found in the rods and three similar pigments in the cones. It is believed that there are three separate sets of cones responding to the primary colours – red, green and blue. Light causes the pigment molecules to split, triggering a nerve impulse which passes along the optic nerve and out of the eye through the blind spot and on to the brain. The chemical change is reversed when the molecules are not stimulated.

The actual mechanism of vision is made more complicated because our eyes are never still. Even when we stare at a fixed object, there is an imperceptible movement so that the images on the retina are never static. These movements lend weight to the argument that we see more by *changes* in the illumination of the rods and cones than by the illumination itself.

Light - The Basic Principles

Scientists were puzzled by the true nature of light and it wasn't until 1864 that the Scottish mathematician James Clerk Maxwell put forward the electro-magnetic theory of light.

Light is one form of electro-magnetic radiation within the electro-magnetic spectrum, and occupies only a small part of this spectrum. In fact our eyes have evolved simply to detect the strongest parts of the sun's radiation. (See illustrations on pages 4–5.)

The whole electro-magnetic spectrum ranges from very short wavelengths, such as X-rays, through to very long wavelength radio waves. The visible part of the spectrum covers wavelengths from 380 to 760 nm (1nm, or nanometre = 10^{-9}m) and our eyes discriminate the various wavelengths in terms of colours. The blue end of our spectrum has short wavelengths while the red has long. On either side of the visible spectrum are the ultra-violet and infra-red radiations which we cannot see, but which we detect by other effects. UV for example is responsible for sunburn, and IR is detected as heat.

All electro-magnetic radiation travels in straight lines at a speed of 300,000 km/s in vacuum. Any wave has a velocity which is a product of its wavelength and frequency ($v = f\lambda$). When passing through materials other than vacuum the velocity is reduced by a factor known as refractive index. At the boundary of two different media the incident lightwaves are either reflected, transmitted or absorbed. If the light strikes the surface at right angles the transmitted light continues in a straight line. However, if it strikes the surface at an angle it will be bent, or refracted. (See Fig. 1.)

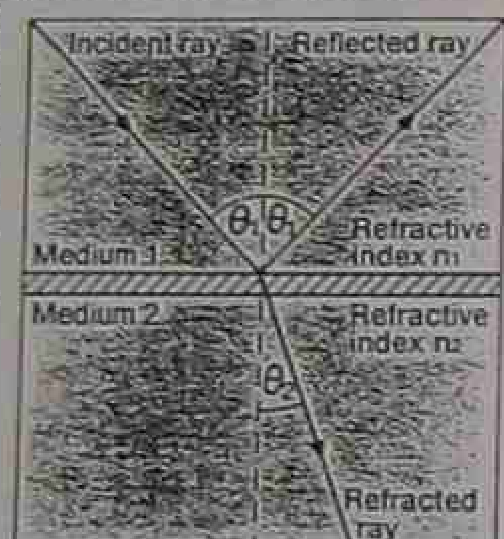


Fig 1 — Refraction/Reflection

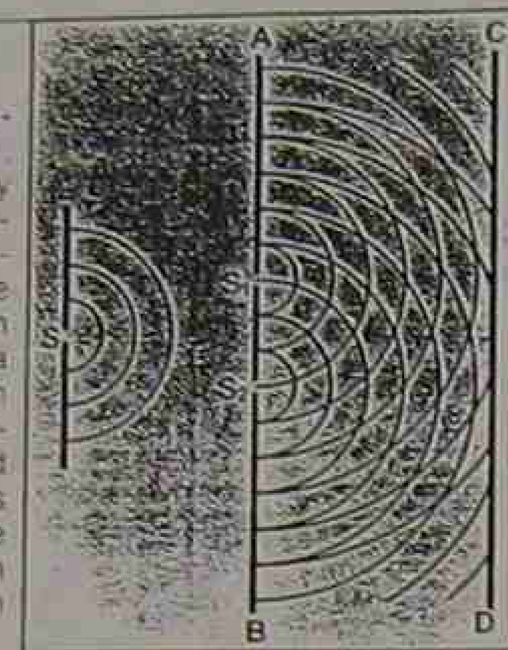
For rays passing from a high to a low refractive index medium, e.g. glass to air, a refracted ray only exists if the angle of incidence is below a critical value otherwise a condition known as total internal reflection takes place.

Fibre optics take advantage of this phenomenon enabling light to be channelled along glass rods and fibres. The technique enables surgeons to examine the insides of our stomachs and lungs and is also being developed as a way of sending many telephone messages on light beams along fibres instead of using wires and cables.

The wave nature of light gives rise to an effect called interference. If two sources having the same wavelength are combined, an interference pattern of light and dark is formed. The pattern is explained by the two light waves being in step in the bright areas and out of step (or opposite) in the dark areas. Interference is used in dichroic filters which only transmit parts of the spectrum. Interference is caused by building up many coated layers whose thickness is a function of the wavelength to be filtered. The rest of the spectrum passes with very little loss. The dichroic filter is therefore much more efficient than conventional pigmented filters.

Another phenomenon resulting from the wave nature of light, is known as diffraction – the bending of light rays around the edges of obstacles. A combination of diffraction and interference is used in the diffraction grating commonly used for examining the spectra of light sources. (See Fig. 2.)

Fig. 2 — **Young's Experiment.** In 1801, Young gave a very convincing demonstration of the diffraction of light when he allowed sunlight from a pinhole, S to fall on a screen, AB, in which there were two adjacent pinholes, S and S. The light waves spread out from the latter to produce an interference pattern on the screen CD.



Later experimenters replaced the three pinholes by narrow and parallel slits and used monochromatic light instead of sunlight.

LIGHT POLARISATION

When light waves vibrate in one plane only, such light is said to be polarised. (See Fig. 3.) The vibrations which cause the wave motion in a ray of light are at right angles to the direction the light is travelling, and in a beam of ordinary light these vibrations occur in all possible directions in that plane. By passing light through a material with a crystalline structure, such that it transmits waves only vibrating in a certain direction, it is possible to produce polarised light, all of whose vibrations are parallel. High quality sunglasses use this principle to reduce glare.

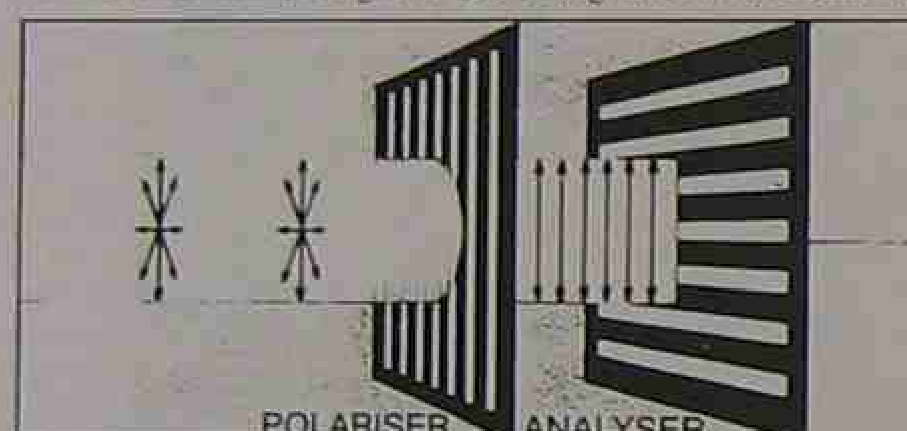


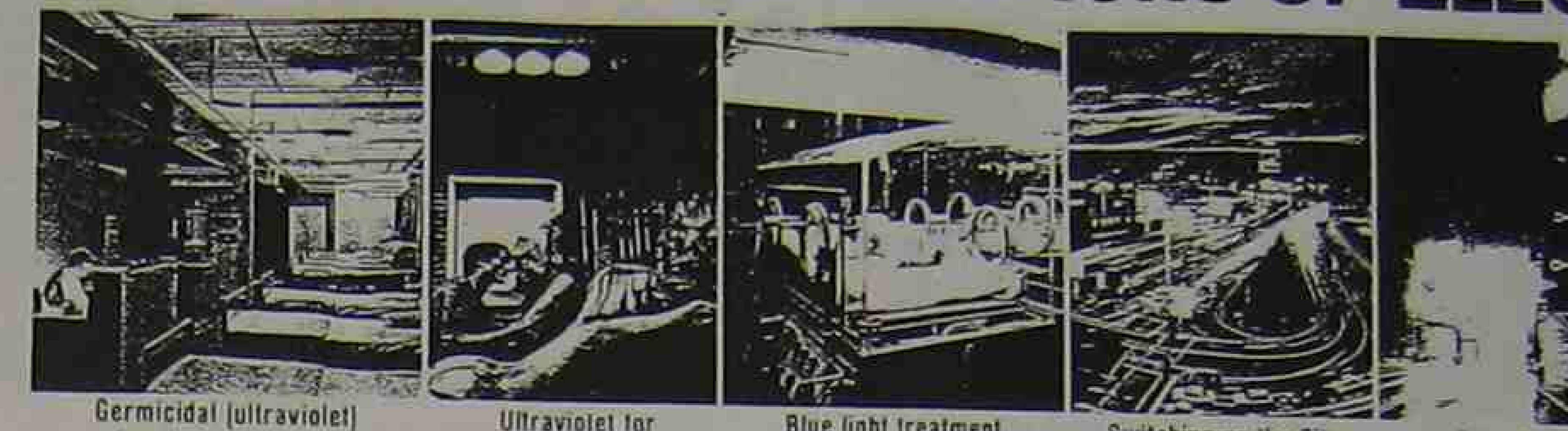
Fig 3 — Light polarisation

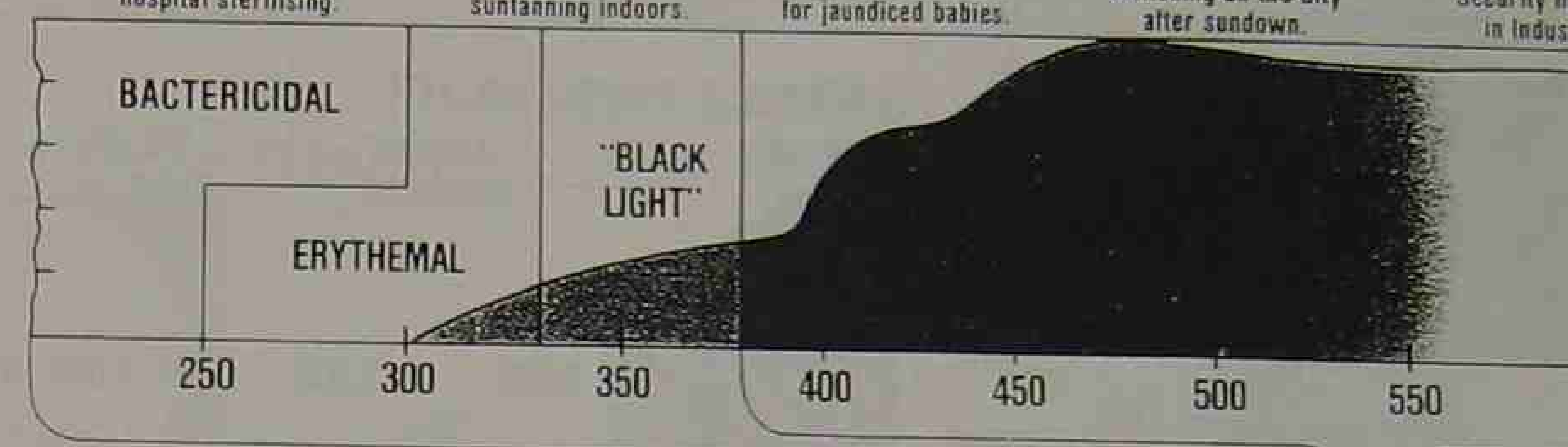
THE NATURE OF COLOUR

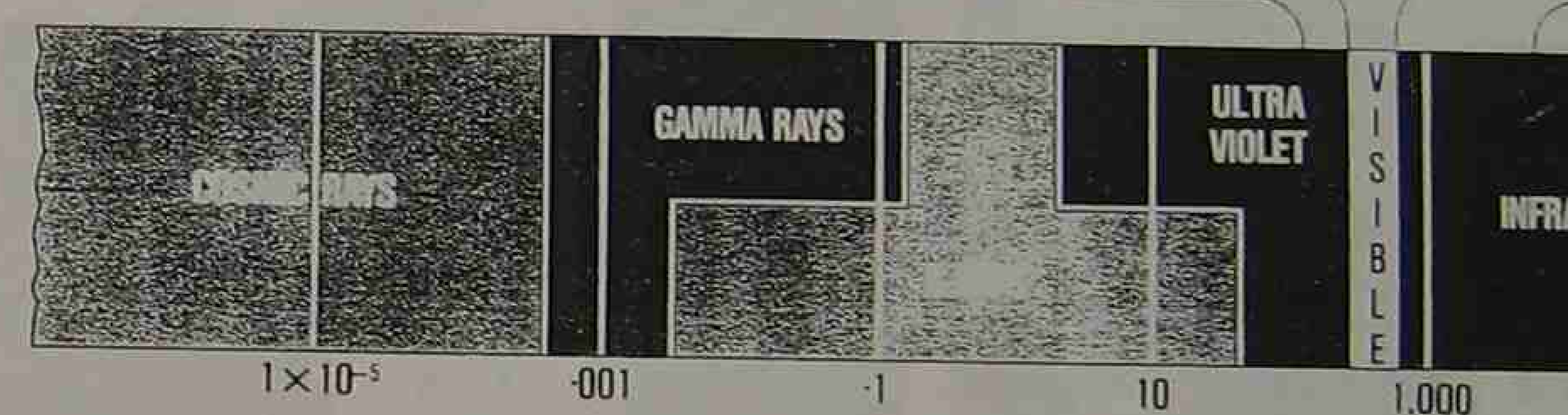
In his famous experiments around 1700, Newton demonstrated how a beam of white light could be split up into a spectrum by means of a prism. He identified seven distinct hues but observed that they merged into one another "so that there appeared as many degrees of colours as there were sorts of rays differing in refrangibility". Newton also observed that the colours could be recombined to give white light. He also showed that colours produced by mixing separate wavelengths could give the same visual effect as an intermediate wavelength. His experiments laid the foundation for the modern science of colorimetry.

A fundamental of colorimetry is that any colour of light can be exactly imitated by a combination of not more than three pure spectral wavelengths of light. Thus the primaries – red, blue and green – could be mixed in different proportions to give a particular colour $c_1C_1 = r_1R + b_1B + g_1G$ where C_1 is the colour to be matched.

APPLICATIONS OF ELEC







ELECTROMAGI

R,B,G are the primaries and r_1, b_1, g_1 and c_1 are the amounts of the respective colours. Another mix could give a colour $c_2C_2 = r_2R + b_2B + g_2G$.

If we now mix c_1C_1 and c_2C_2 to give $c_3C_3 = r_3 + b_3B + g_3G$ then another principle of additive colour mixing says that $r_3 = r_2 + r_1$ and $b_3 = b_2 + b_1$ and $g_3 = g_2 + g_1$.

The equation $cC = rR + bB + gG$ involves both quality and quantity. For a match, the quantities of light must be equal so $c = r + b + g$. Dividing both sides by c give $C = RR + BB + GG$

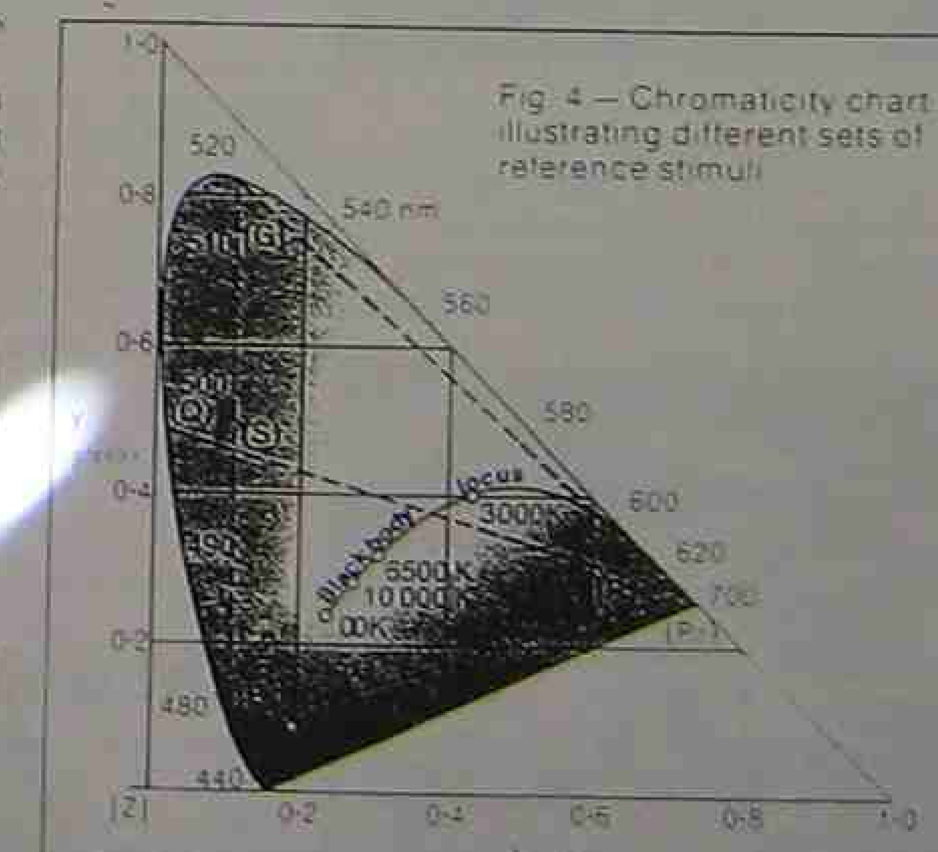
where $R = \frac{r}{r + b + g}$ etc.

This in turn leads to a further equation $R + G + B = 1$ and R, G and B are called the chromaticity co-ordinates of C and can be plotted on a two dimensional chart known as the chromaticity diagram or colour triangle. (See Fig. 4.)

COLOUR TEMPERATURE

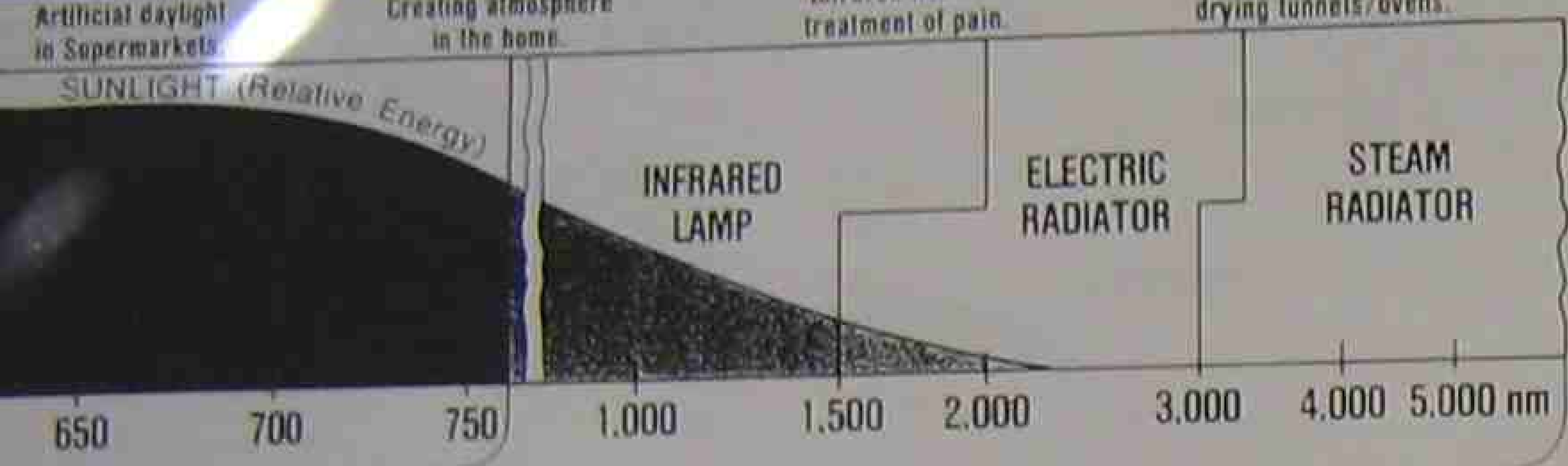
When a black body is heated it radiates energy or radiation in a characteristic manner which is dependent upon and related to its temperature. Certain materials for example such as those used as lamp filaments behave in a similar way and it has been found useful to classify the colour of certain "white" light sources by specification of their "colour temperature".

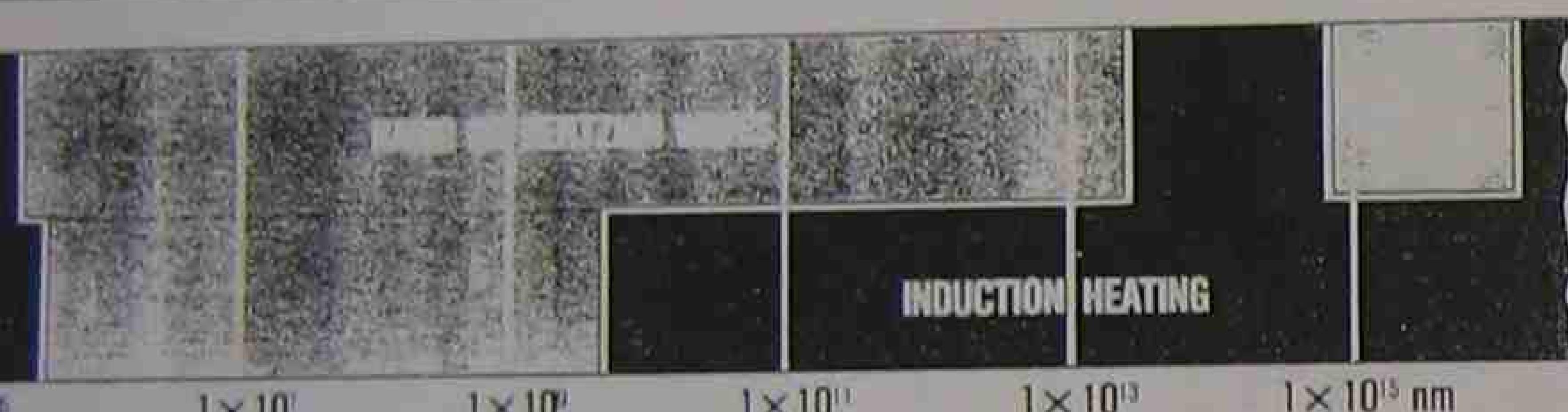
At sufficiently high temperatures they emit red light and as the temperature increases the emission becomes whiter. The colour coordinates of a black body at various temperatures can be plotted in the chromaticity diagram and the resulting line is called the "black body locus" (Fig 4).



So far we have considered light sources, but we must also consider the colour of light reflected from surfaces like this paper for example. The colour of any object is

...OMAGNETIC RADIATION





...IC SPECTRUM

...commonly the hue of the most strongly reflected wavelengths. We call this colour **RED** because the ink absorbs the other wavelengths when we view it in white light. However it is important to consider the spectrum of the source illuminating the page. If you were standing under a sodium street light this page would look mainly brown and black – why?

Surface colours therefore depend on subtractive processes. If we mix pigments we cannot apply the principles of colour addition. Thus if we mix blue and yellow pigments we produce green because that is the only part of the spectrum reflected by both pigments (Fig. 5). If we did the same thing with two light sources, what colour would we get?

The most useful subtractive primaries are the complementaries of the additive primaries. They are cyan, magenta and yellow which if mixed in the right amounts

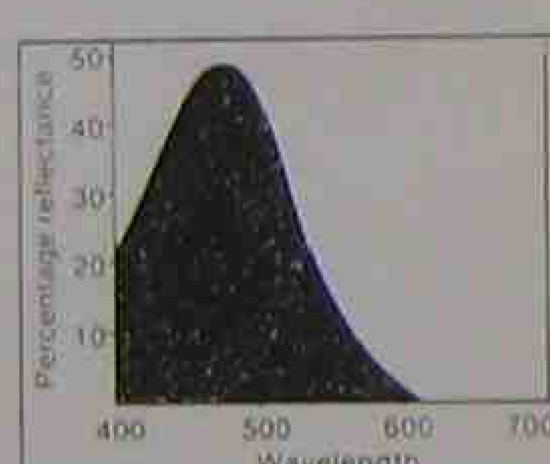


Fig. 5 – Spectral reflectance curves for blue and yellow coloured pigments and their subtractive mixture

produce black and were used in printing this sheet. If you examine the illustrations with a powerful magnifying glass, you will see how the different colours are obtained by varying the size of dots of cyan, magenta and yellow. Black is also used to improve the result and overcome the limitations of the printing process.

Basic light units & terminology

Luminous Intensity (I). Early attempts to measure light were by comparison with the commonest source of artificial light – the candle. The luminous intensity of a candle perpendicular to the vertical flame was called one candlepower. It is a directional concept equivalent to the amount of light contained in a small solid angle in the direction under consideration (i.e. lumens/steradian). The present unit, the candela (cd), is approximately equal to 1 candlepower. The standard of light is a black body radiator at the temperature of freezing platinum which has a luminance of 6×10^5 cd/m².

Luminous Flux (F) describes the quantity of light emitted by a source or received by a surface. The unit – the lumen – is the luminous flux emitted within a unit of solid angle (steradian) by a point source having a uniform intensity of one candela in all directions.

Luminance (L) is a measure of the physical brightness of a surface. It is related to the amount of light emitted by a source or reflected by an object. The unit is the candela per square metre (cd/m²) and again is a directional concept as it may vary with the direction being considered.

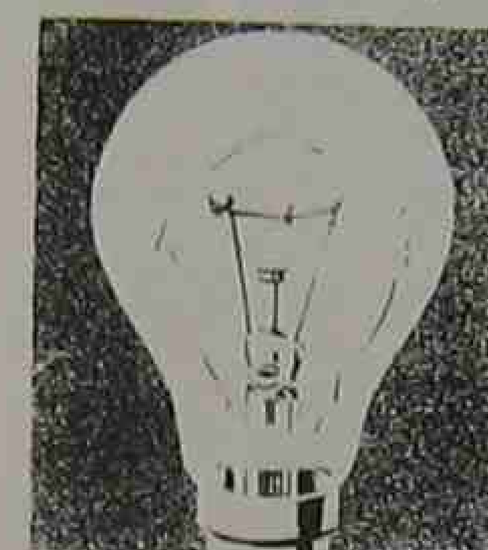
Illuminance (E) is a measure of the light falling on a surface expressed in lumens/m² or lux. The old "foot candle" is still used in some parts of the world and is approx. 0.1 lux.

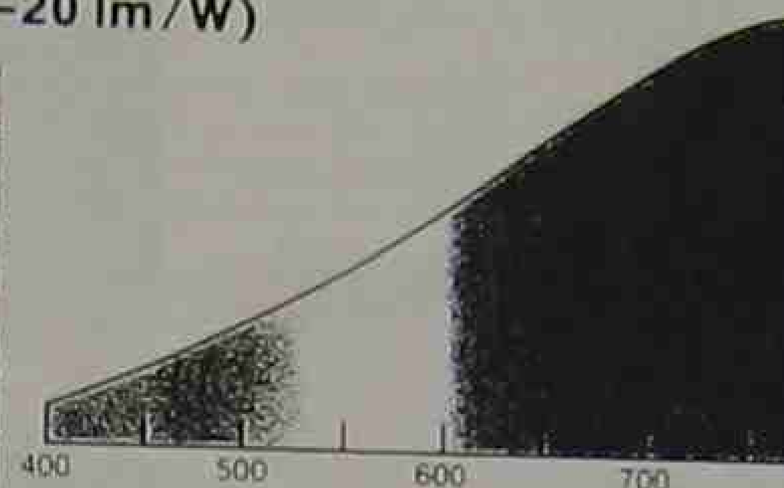
Using Light Today

Although our domestic filament lamp looks superficially like Edison's lamp (see back page), there have been many improvements, notably the replacement of the delicate carbonised thread filament with a strong one made of tungsten. Lighting engineers are constantly striving to increase the efficiency of lamps and the quality of light they produce. The efficient conversion of electrical power to light grows in importance as world energy sources are limited. In many applications we can compromise between the quantity and quality of light – street lighting is a good example. Many different types of lamp are made. They fall into two main categories – filament and discharge. Some typical Philips lamps are shown here. You can compare their efficiencies by the number of lumens per watt they produce, and the quality of light from their spectra.

FILAMENT LAMPS

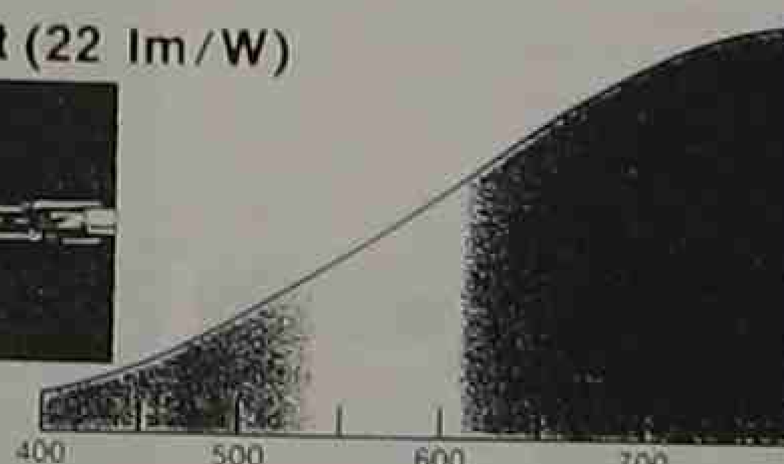
Incandescent (10–20 lm/W)





Incandescent bulbs have low efficacy, but good colour properties. Mass-production means low cost, and therefore extensive use.

Halogen Floodlight (22 lm/W)

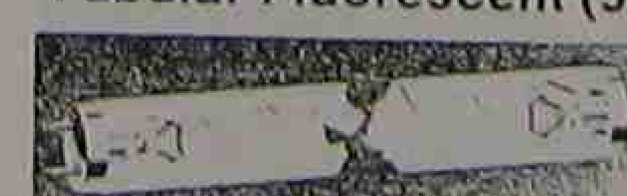


The halogen lamp is a tungsten filament lamp which uses a small amount of a halogen element. Evaporated tungsten from the filament and halogen atoms combine, and when the compound returns to the proximity of the filament the tungsten is redeposited and the halogen released.

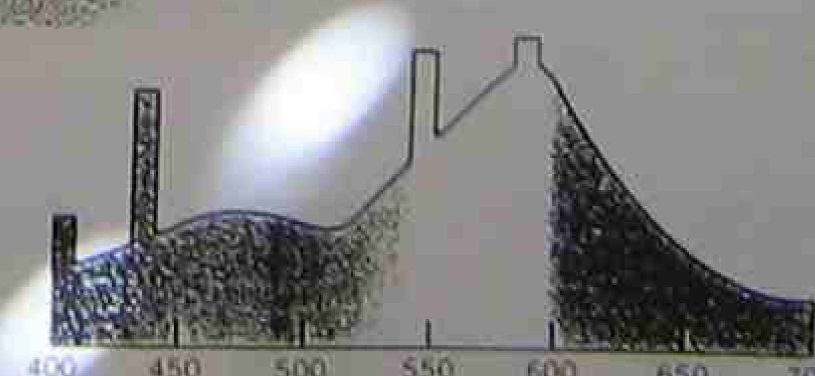
DISCHARGE LAMPS

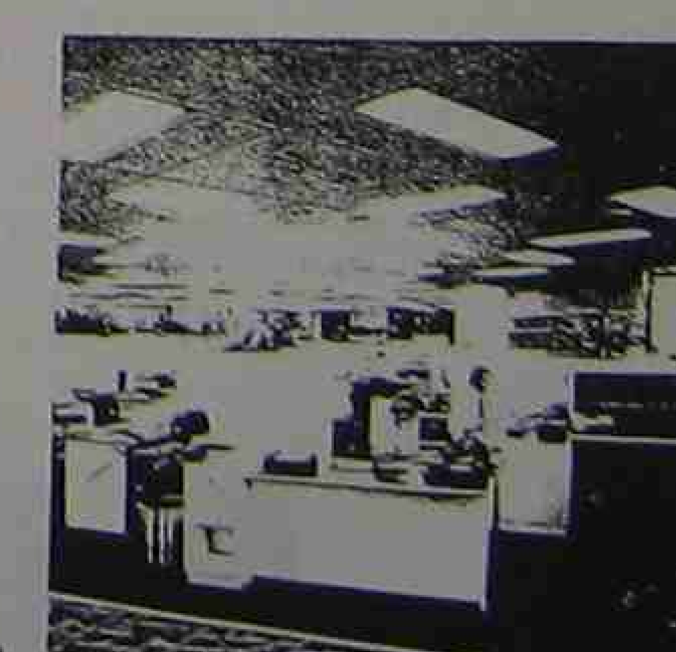
When an electric current is passed through a gas or vapour an electrical discharge or arc takes place. Electro-magnetic radiation, including light, is produced in an arc, and the wavelength depends on the gas or vapour and their pressures. If the radiation produced is ultraviolet radiation a fluorescent coating on the lamp envelope may be used to convert it to visible radiation, or light. Different phosphor blends are available to produce different coloured white light, ranging from "warm" to "cool".

Tubular Fluorescent (50–90 lm/W)

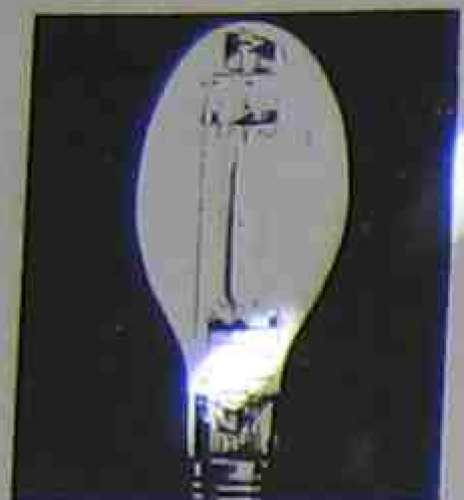


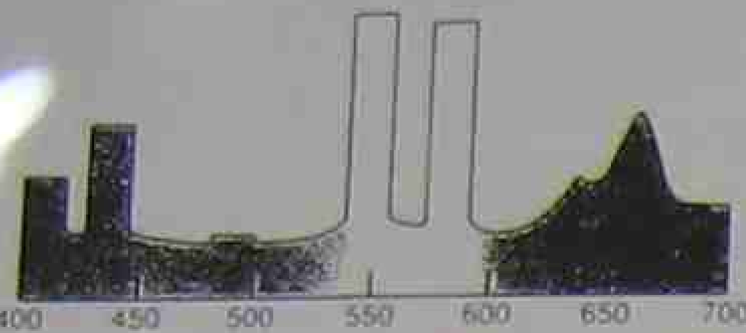
The fluorescent lamp uses an electric discharge in mercury vapour at very low pressure to produce ultraviolet radiation. This radiation is converted to light by a fluorescent powder coating on the lamp wall.





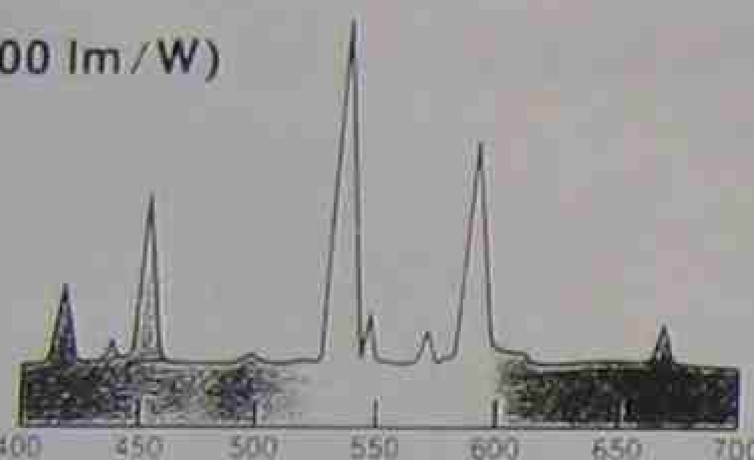
High Pressure Mercury Fluorescent (50–60 lm/W)





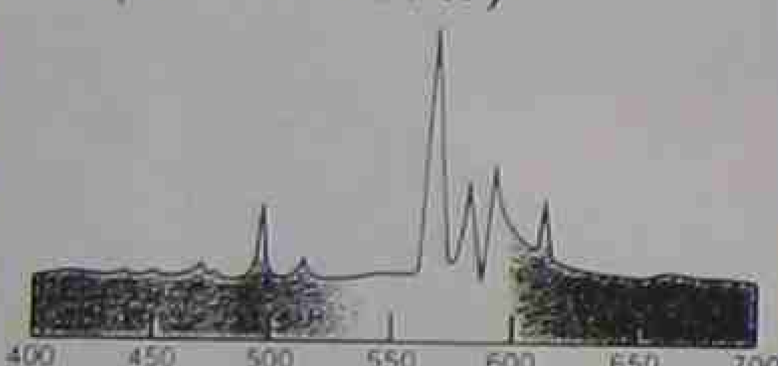
This lamp is a high pressure mercury vapour source which produces light both directly and by using a phosphor coating. It has good efficiency and reasonable colour.

Metal Halide (75–100 lm/W)



The addition of metal halides (such as sodium, thallium or indium iodides) has almost doubled the light output of mercury discharge lamps as well as improving colour quality.

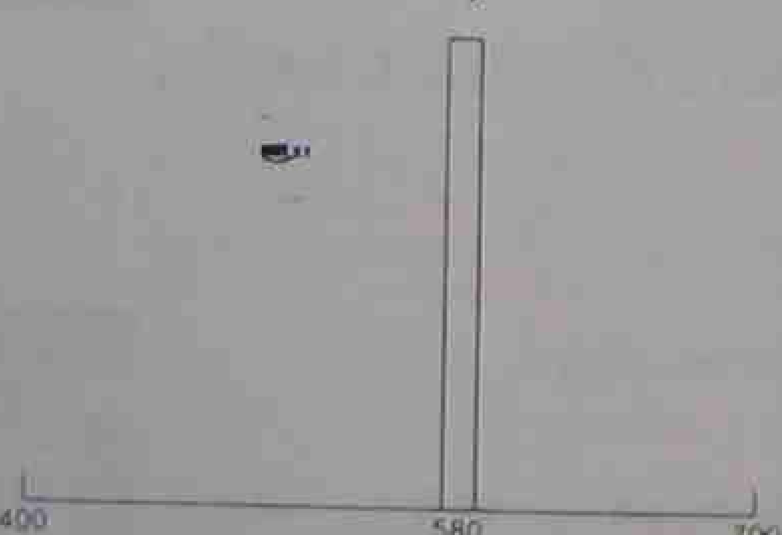
High Pressure Sodium (100–150 lm/W)

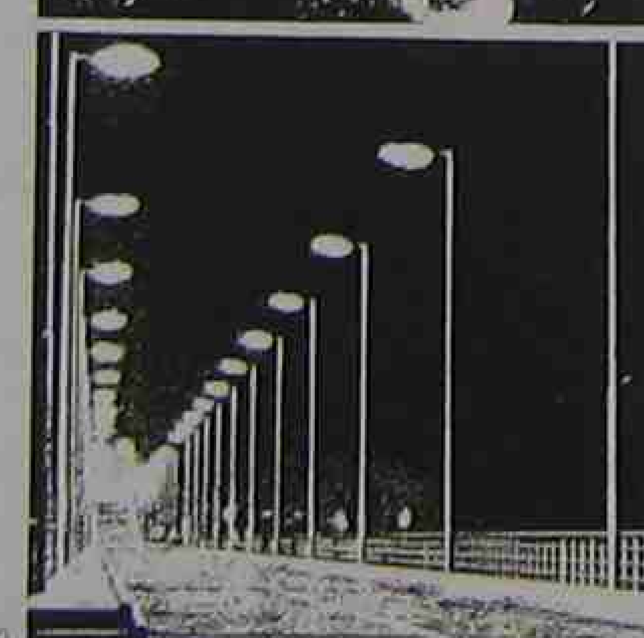


Sodium can be used as a light producing vapour. Under high pressure conditions, the colour rendering is reasonable but efficiency is much higher than for mercury lamps.

Low Pressure Sodium (150–200 lm/W)

The output is at a single wavelength (i.e. monochromatic radiation) to which the eye is extremely sensitive. This source is ideal where colour discrimination is not as important as efficiency.





LIGHT

The History of Lighting

Man has battled with the dark since time began, yet it is only in the past 100 years that we have been able to produce artificial light without relying on a flame. Having produced fire, prehistoric man struggled to keep the flame burning brightly for as long as he could. It didn't take him long to discover that animal fat burned brightly and the first lamps, consisting of hollowed stones with vegetable fibre wicks, appeared over 80,000 years ago.

Until some 200 years ago, progress was almost non-existent. The candle is mentioned in the Old Testament of the Bible. The Romans and Greeks probably knew as much about lighting as was known in the early 19th century.

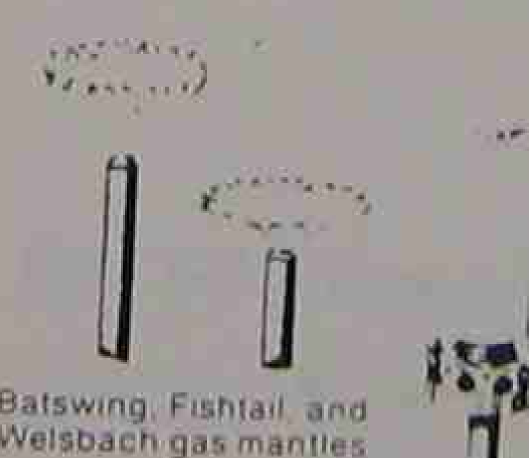
The next major step was to gas lighting in the late 1700s. In 1765, Lord Lonsdale in England piped coal gas from his mine to his office for lighting. Lack of purification and the meagre light delayed the popularity of gas lighting until Welsbach developed the incandescent mantle in the late 1880s. Here the lighting effect depends on the mantle being heated to incandescence rather than the flame itself.

Early experiments with electric lighting were hindered by the lack of large-scale permanent sources of electricity. The carbon arc was demonstrated by Sir Humphrey Davy in 1810, but it wasn't until Faraday discovered the principle of electro-magnetism that the electrical industry was born. The first permanent installation of electric arc lighting was in a British lighthouse in 1862.

Many scientists attempted to produce light from the heating effect of an electric current, but were hampered by the rapid oxidation of the filaments they used which were mainly of platinum.

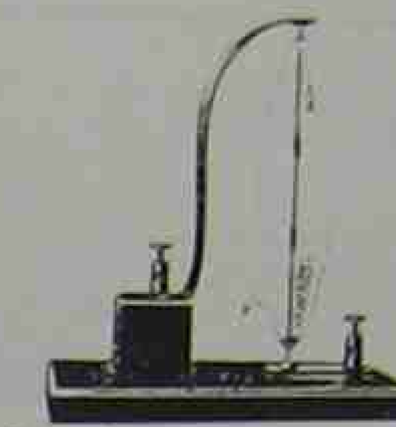
The first patent was granted to an Englishman, Frederick De Moleyns, in 1840 for an ingenious lamp relying on charcoal bridging a small gap between two platinum wires. However, the lamp proved impractical due to rapid blackening from the incandescent charcoal.

The Russian, Lodyguine, produced an incandescent lamp using graphite operating in a nitrogen-filled globe. Two hundred of his globes were installed in the St. Petersburg Dockyard in 1872, but the lamps only had a life of twelve hours.



Batswing, Fishtail, and Welsbach gas mantles

The first practical incandescent lamps were produced by two scientists working independently, Edison in America, and Swan in England. Both were prolific inventors. Edison is probably best known for his invention of the phonogram or record player, while Swan was responsible for the bromide process used in photography.



Swan Carbon filament lamp.

Edison's, lamp, 1879.

It is probably true to say that while Swan made the first practical lamp, it was Edison who had the vision to see how electricity could be distributed so that maximum use could be made of the electric lamp. The lamp itself was only part of Edison's concept.

Edison reasoned that from a distribution point of view, a high resistance lamp was needed. Other attempts had followed the arc concept relying on low voltages and high currents. Edison worked on the opposite idea and his first lamp burned steadily for 45 hours on October 21st 1879, leading to a patent on January 27th 1880. The principles he outlined then are practically the same as those used today with improvements only in the construction of the filament.

Philips first lamp factory, Eindhoven, 1891

It was eleven years later that Gerard Philips bought a buck-skin factory in Eindhoven in the Netherlands, and equipped it to make electric lamps. Manufacture started in 1892, and by 1895 production had reached 109,000 lamps. By the turn of the century, Philips had become the third largest manufacturer of lamps in Europe and in 1916 was producing 80,000 lamps per day. The company established its own research department in 1914, and after the first world war started to expand its range of products into the making of X-ray tubes and radio valves. Today, Philips is possibly best known for its involvement in the broadcasting and television industry, but lighting still forms a major part of its activities.

Industrial Sensors.

Topic - LIGHT SOURCES - ASSORTED

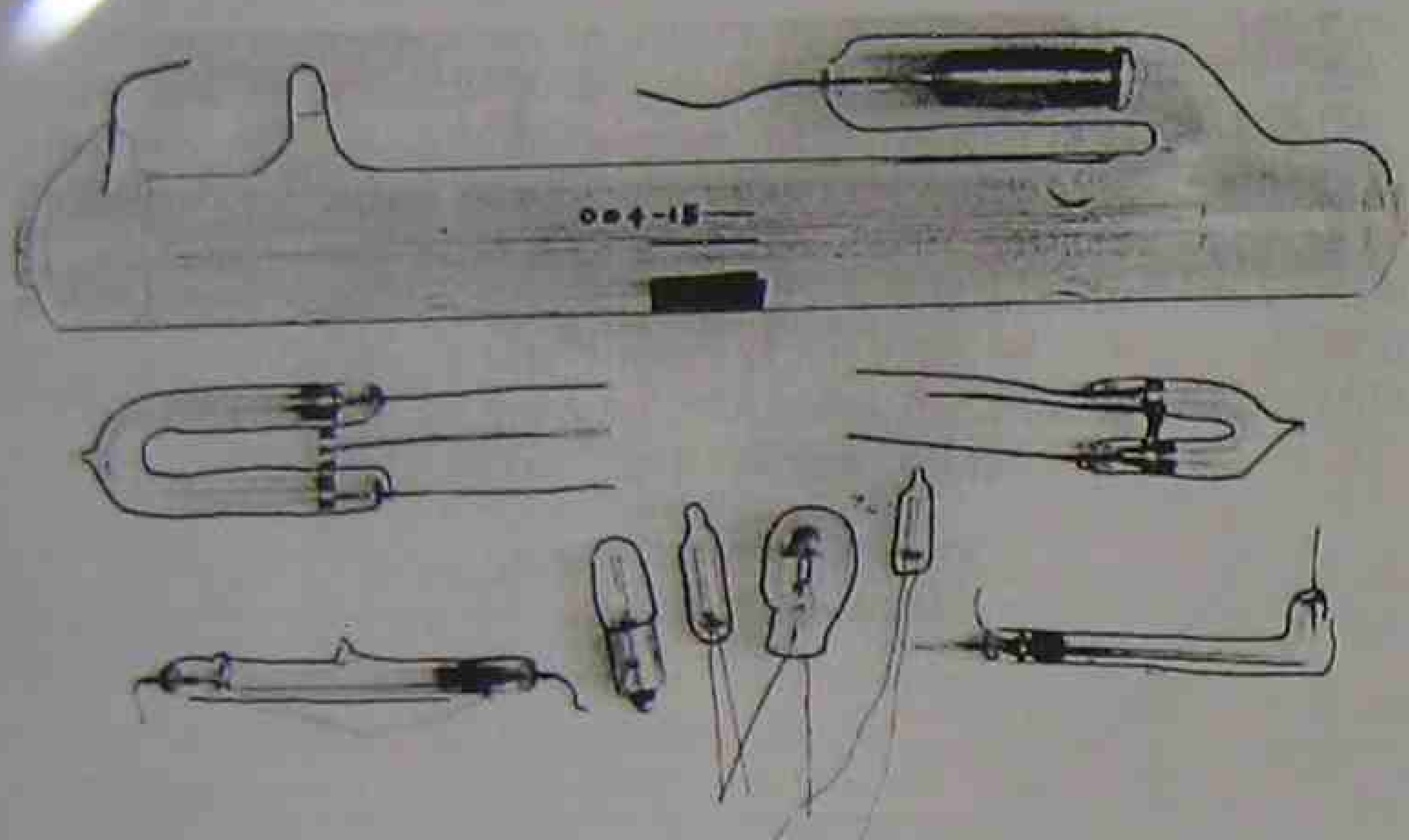
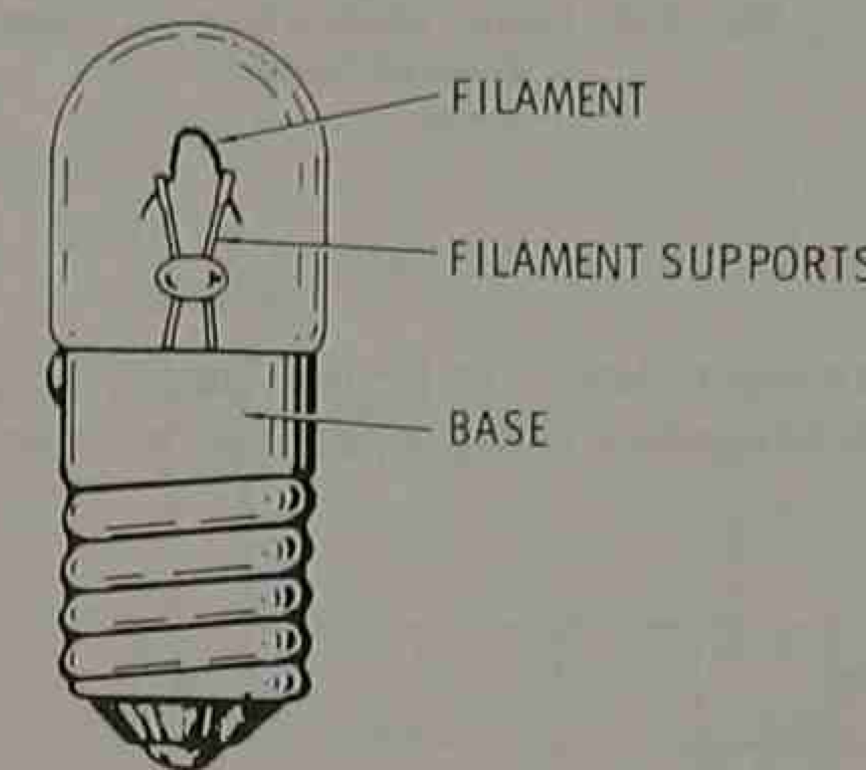


Fig. 3-18. Helium-neon laser tube (top) and assortment of neon, argon, and xenon lamps.

Industrial Sensors.

Topic - INCANDESCENT LAMP



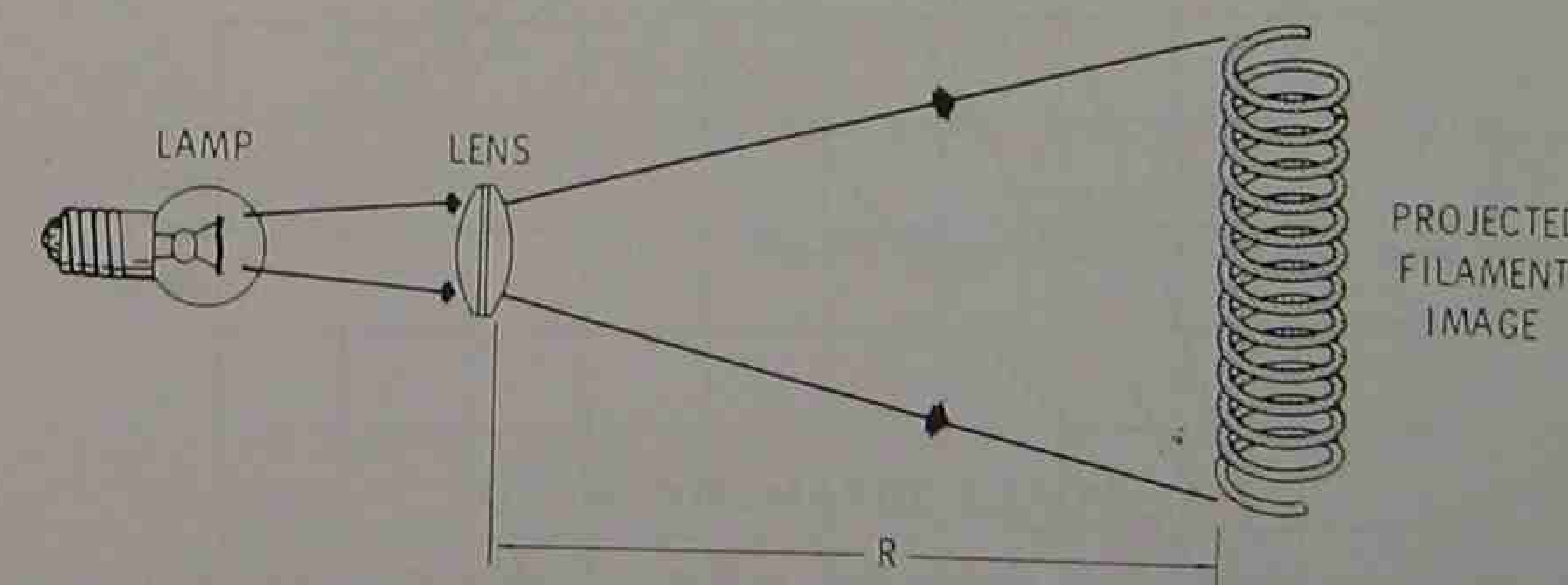


Fig. 3-3. Filament image projected by focused incandescent source.

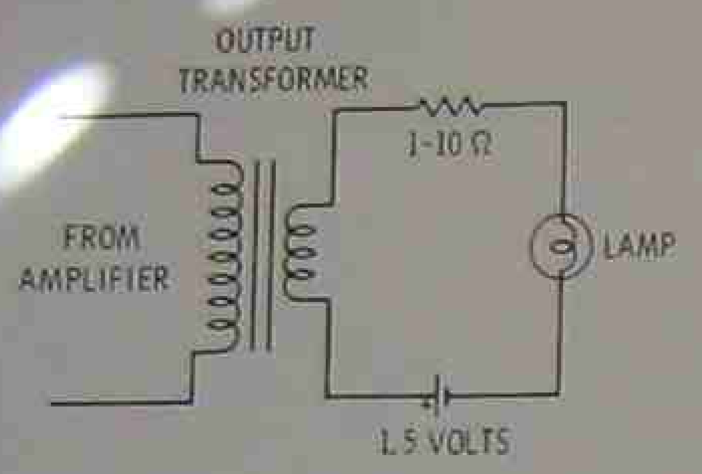


Fig. 3-4. Direct modulation of incandescent lamp.

The spectral output of a tungsten lamp is broad band, and Fig. 3-5 shows the output of a tungsten lamp operated at several color temperatures.

Fig. 3-5. Tungsten lamp spectral output versus filament color temperature.

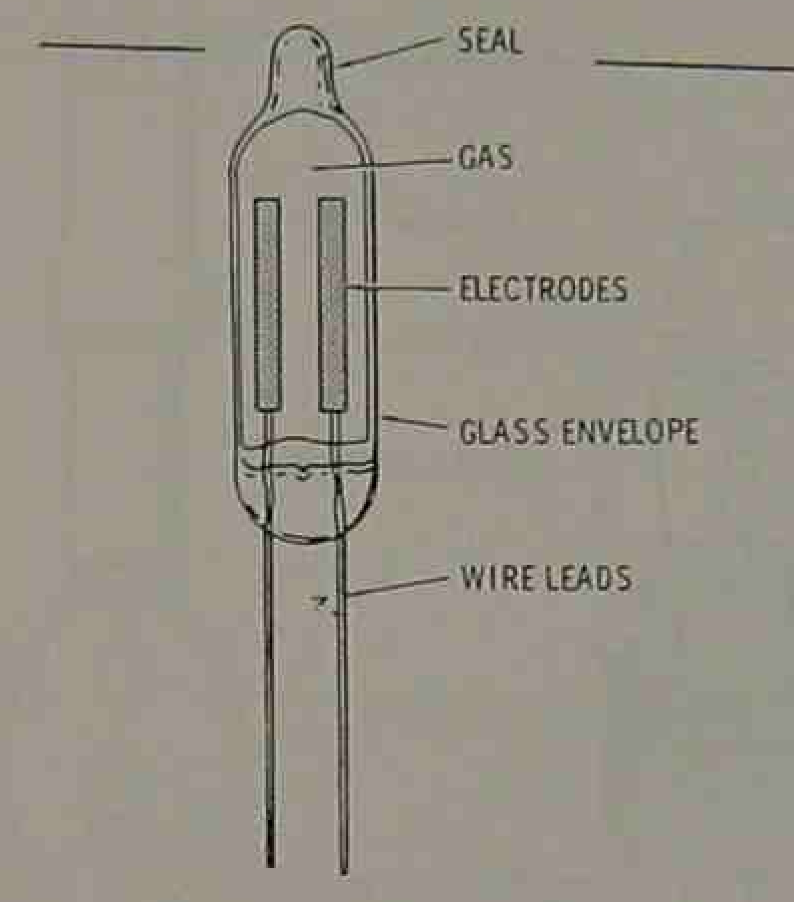


Fig. 3-6. Glow-lamp construction.

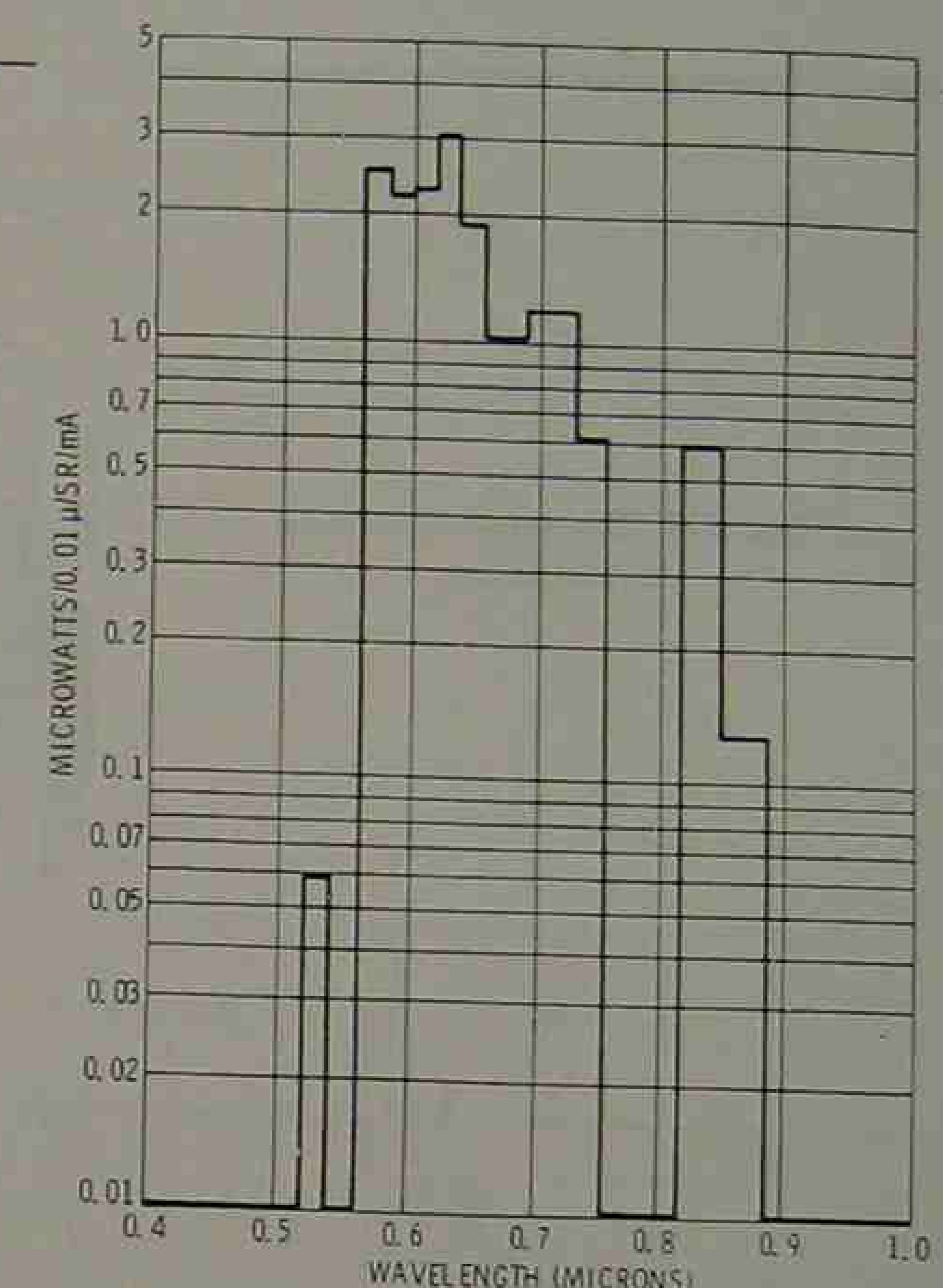


Fig. 3-7. Spectral output of a neon lamp.

GLOW-DISCHARGE LAMPS

The glow lamp shown in Fig. 3-6 consists of a glass envelope containing two or more electrodes and filled with a gas capable of being ionized. The most common glow lamps contain neon or argon. Neon produces a yellow-red range of wavelengths

Industrial Sensors.

Topic - ARC DISCHARGE LAMP

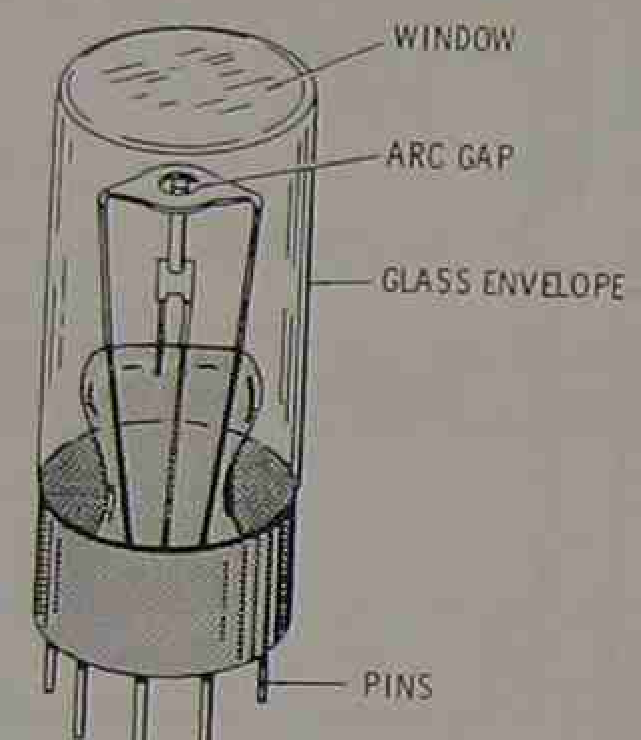
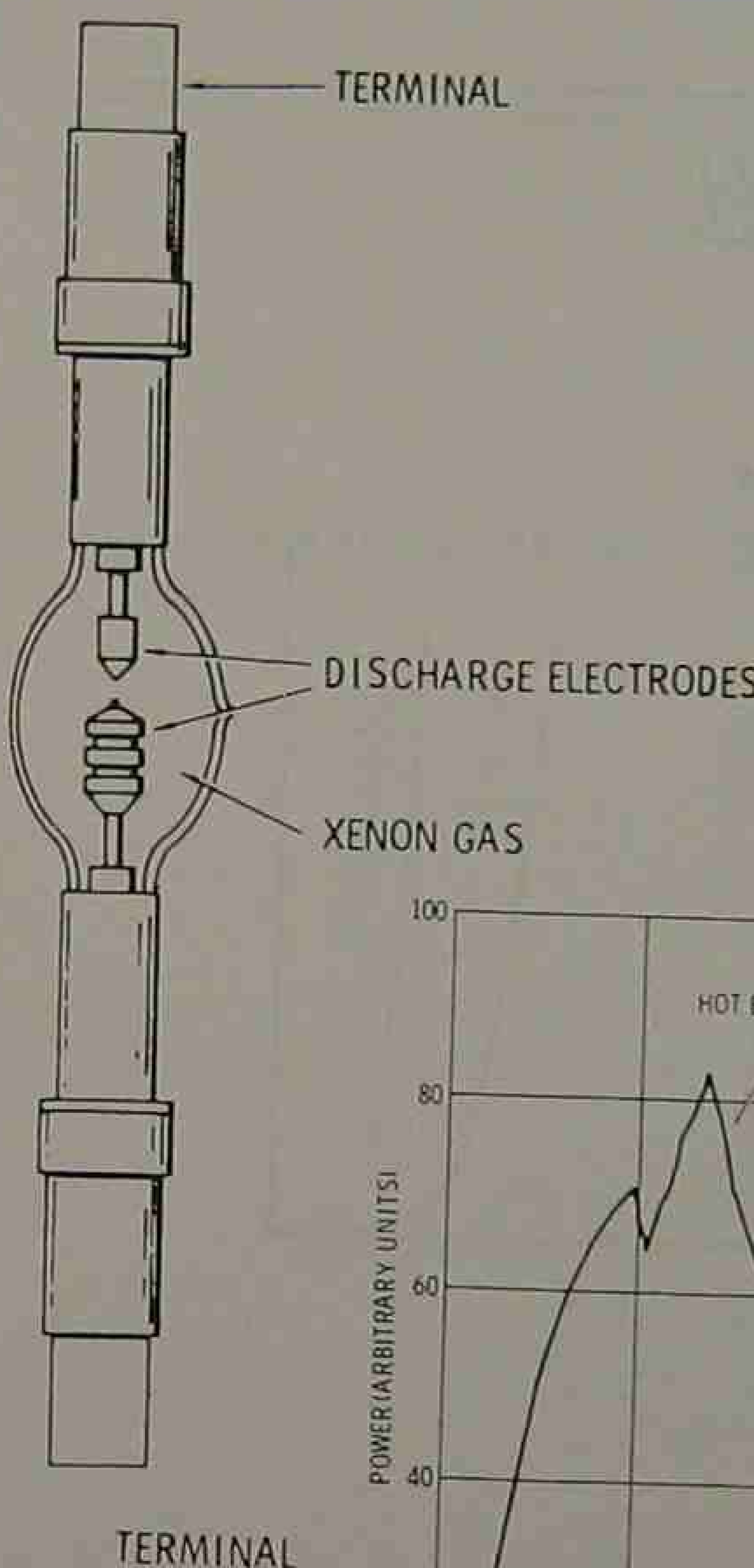


Fig. 3-9. Zirconium arc lamp construction.

Industrial Sensors.

Topic - XENON DISCHARGE LAMP



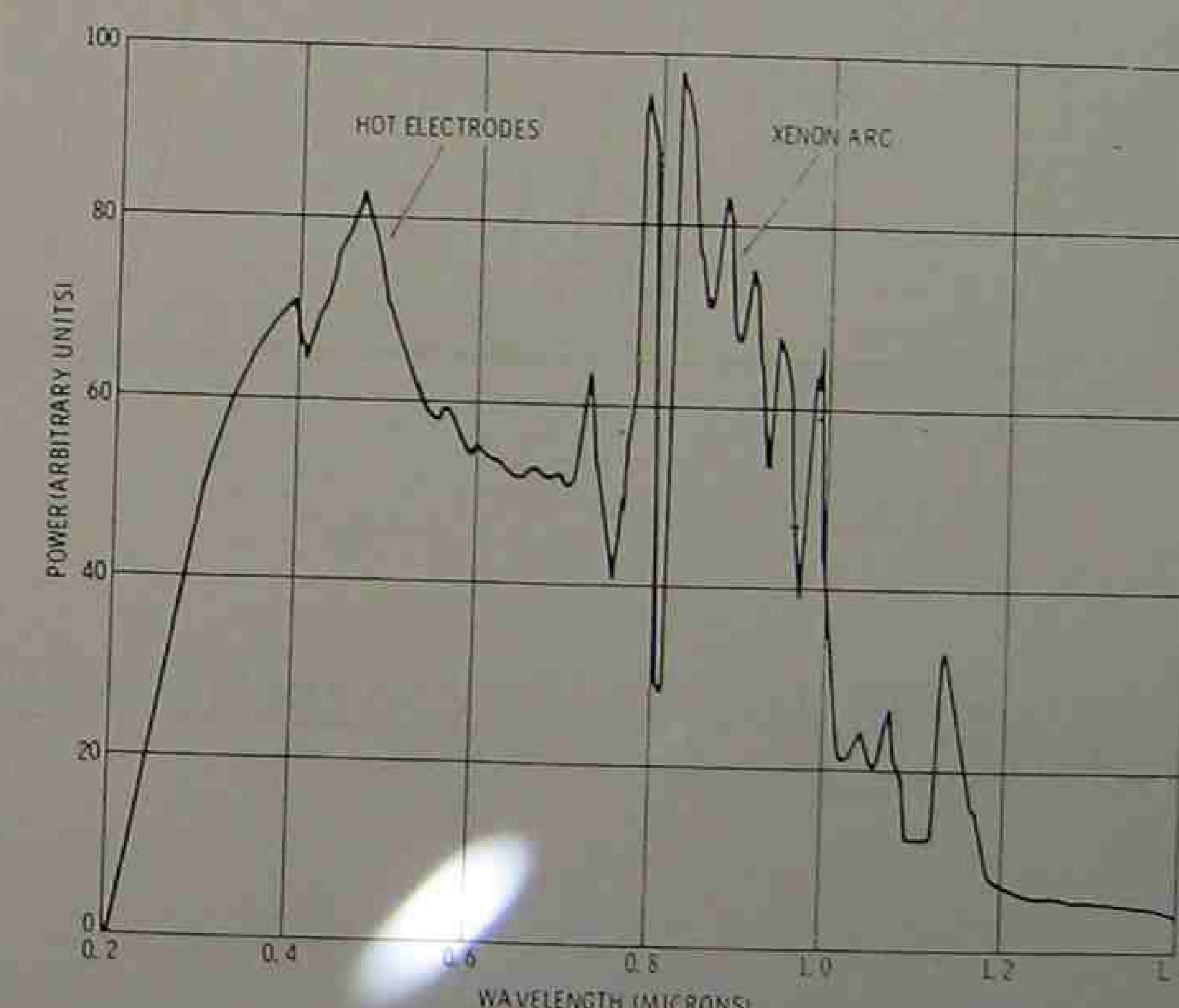
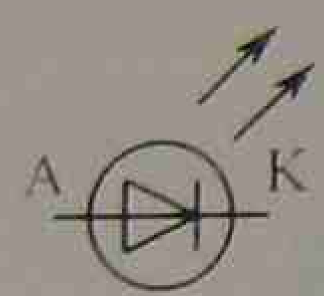


Fig. 3-11. Typical xenon arc lamp spectrum.

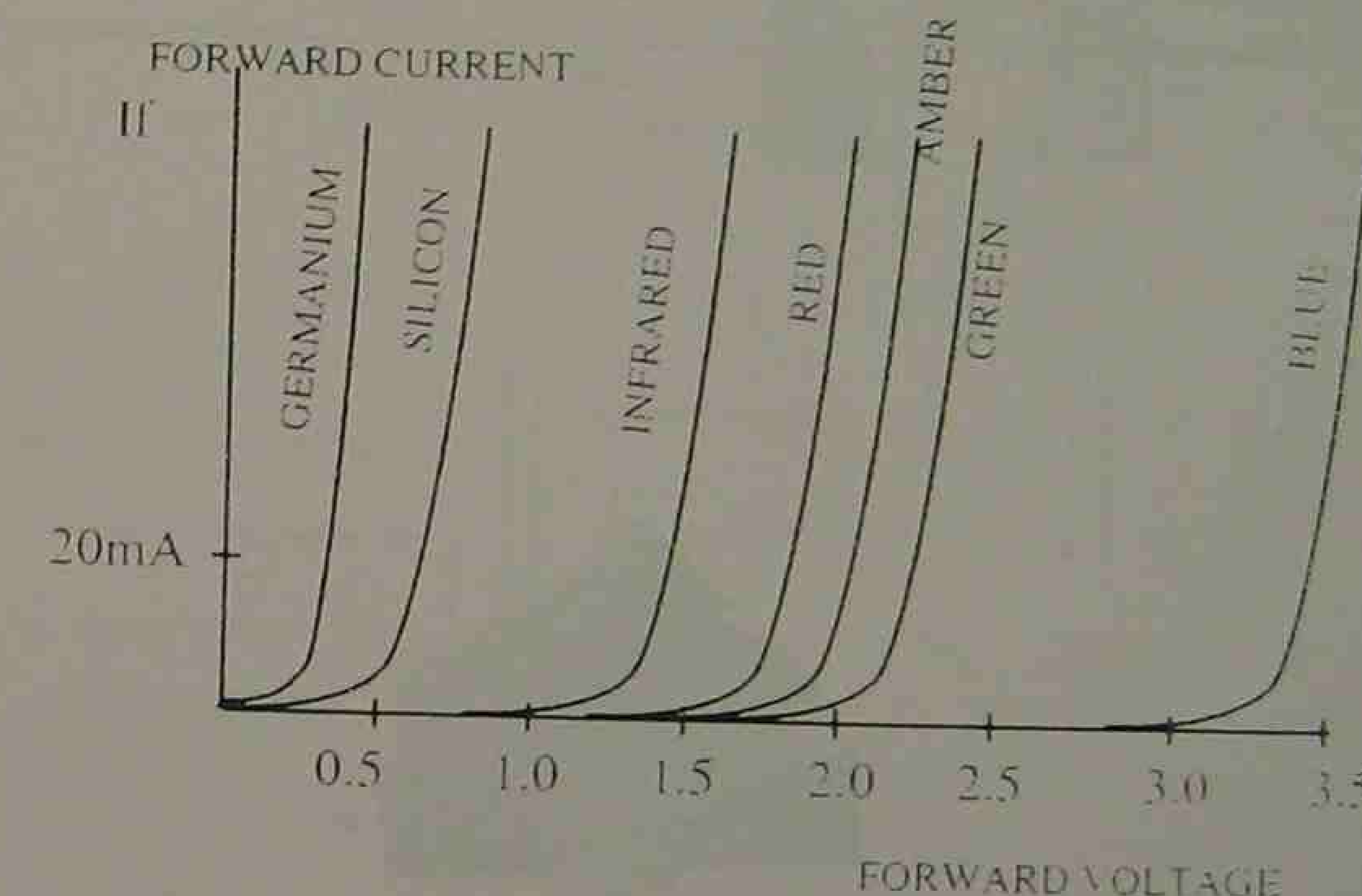
LED

LIGHT EMITTING DIODE

LED SYMBOL



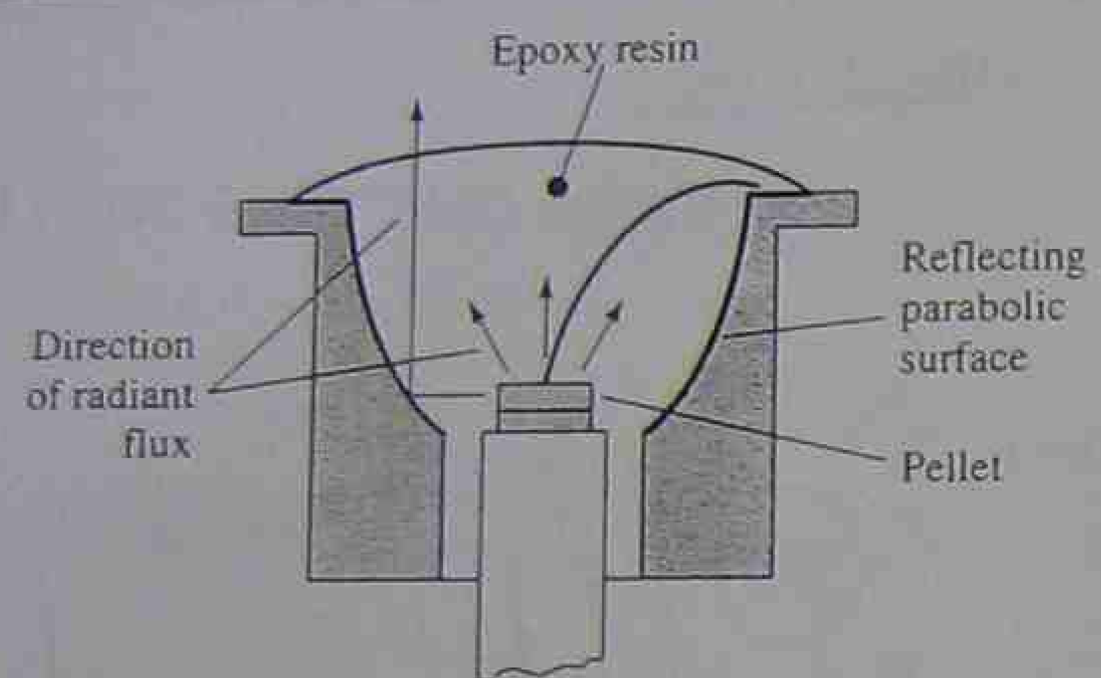
LEDs (cont.)



FORWARD CHARACTERISTICS OF LEDs AND STANDARD Si AND Ge DIODES

Industrial Sensors.

Topic - LED CONSTRUCTION



(a)

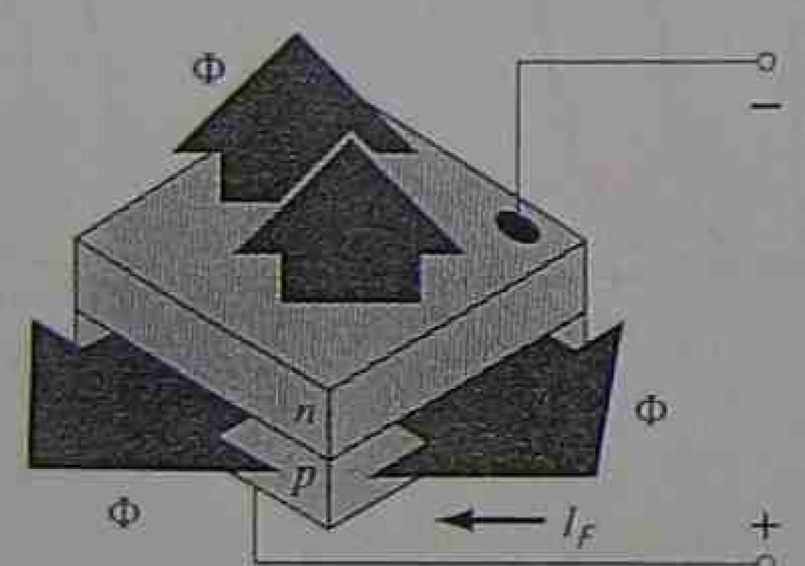
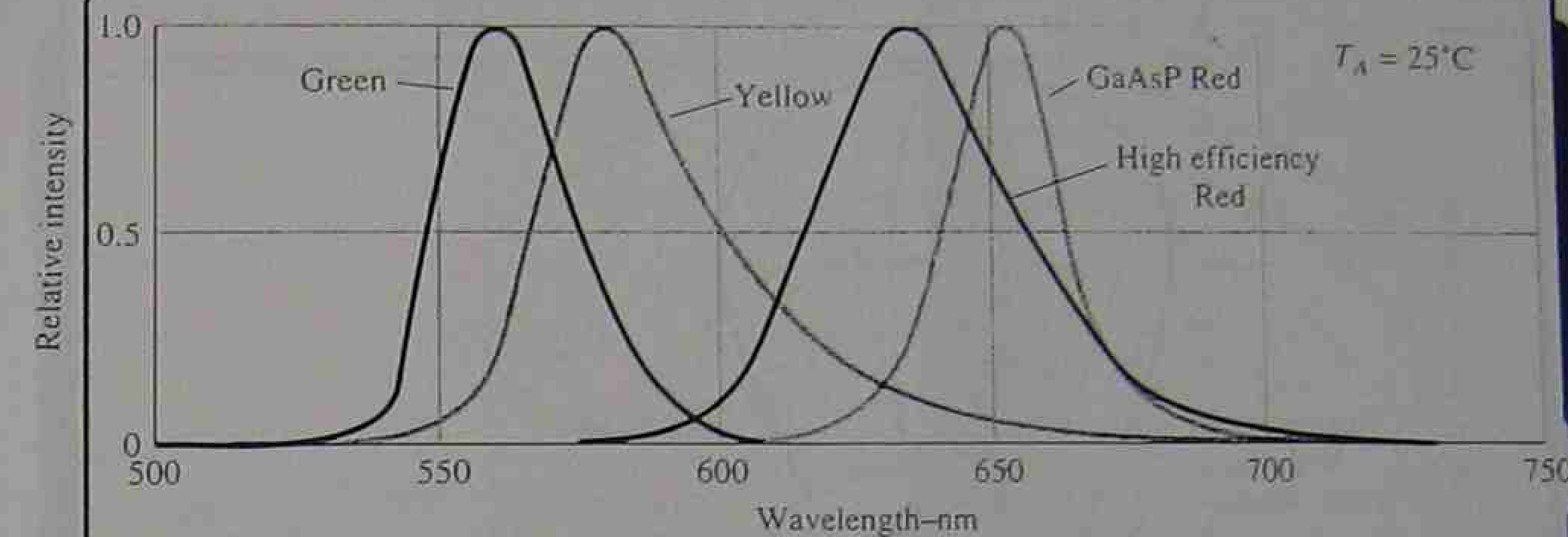
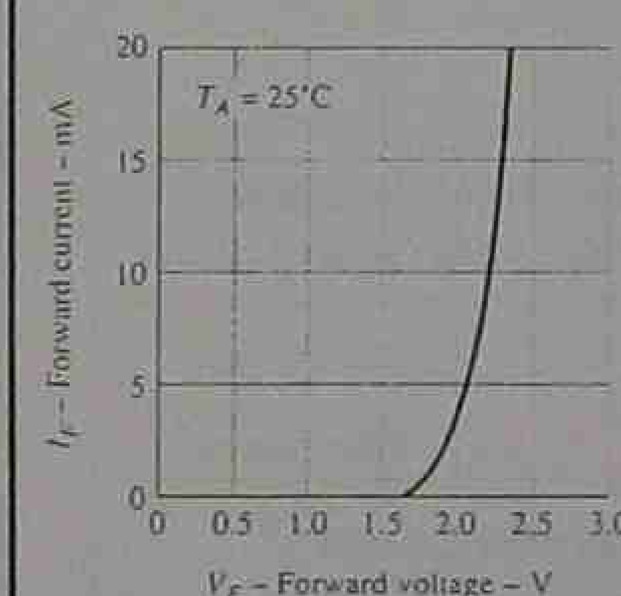


Figure 20.31 General structure of a semiconductor IR-emitting diode. (Courtesy RCA Solid State Division.)

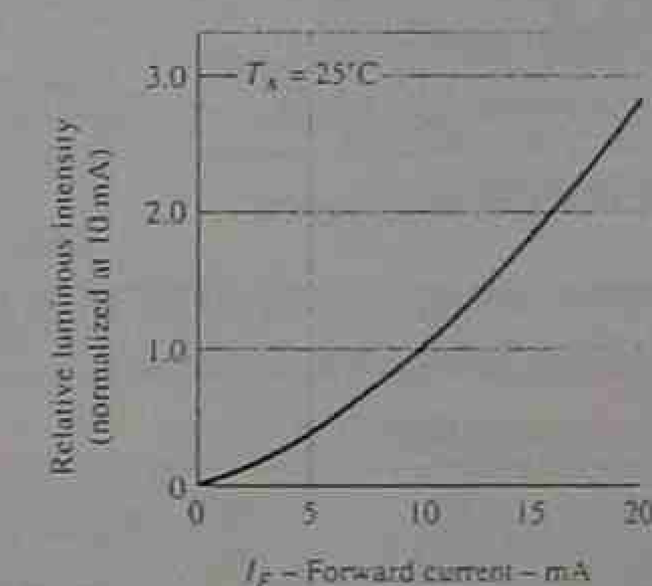
Industrial Sensors.

Topic - LED CHARACTERISTICS

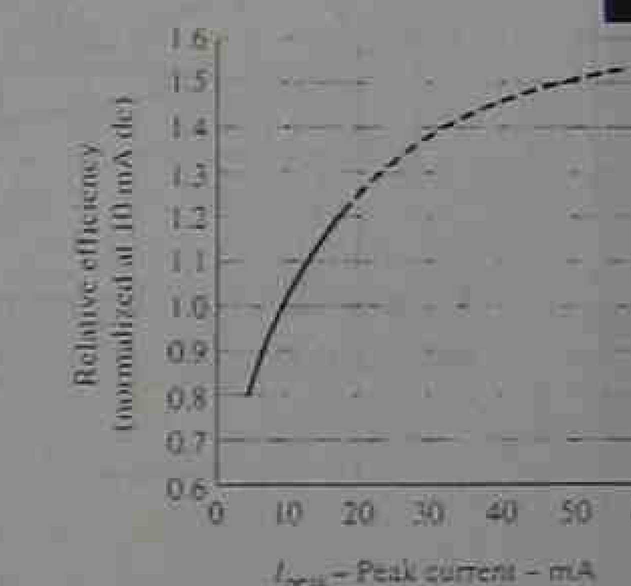




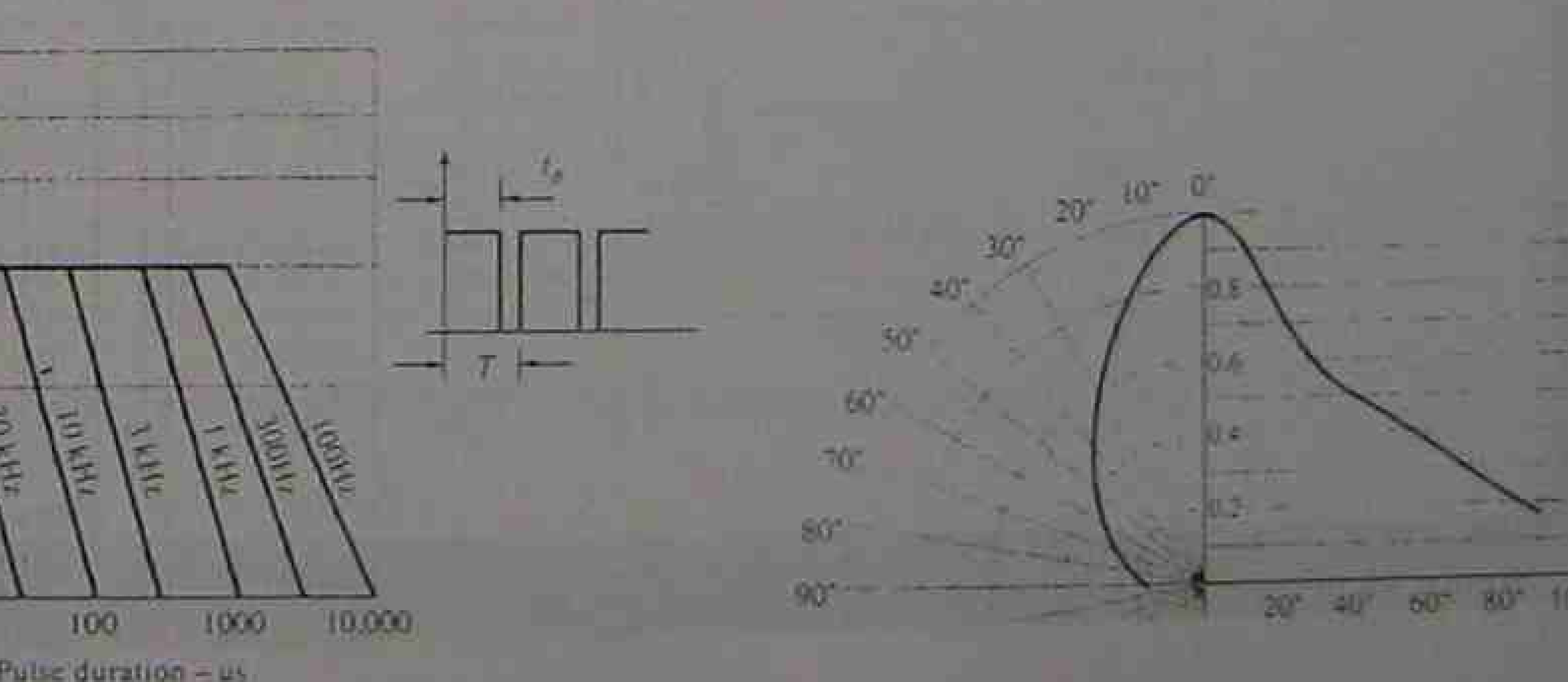
(e)



(f)



(g)



(h)

(i)

Figure 1.55 Continued

Industrial Sensors.

Topic - LED - I.R. EMITTER

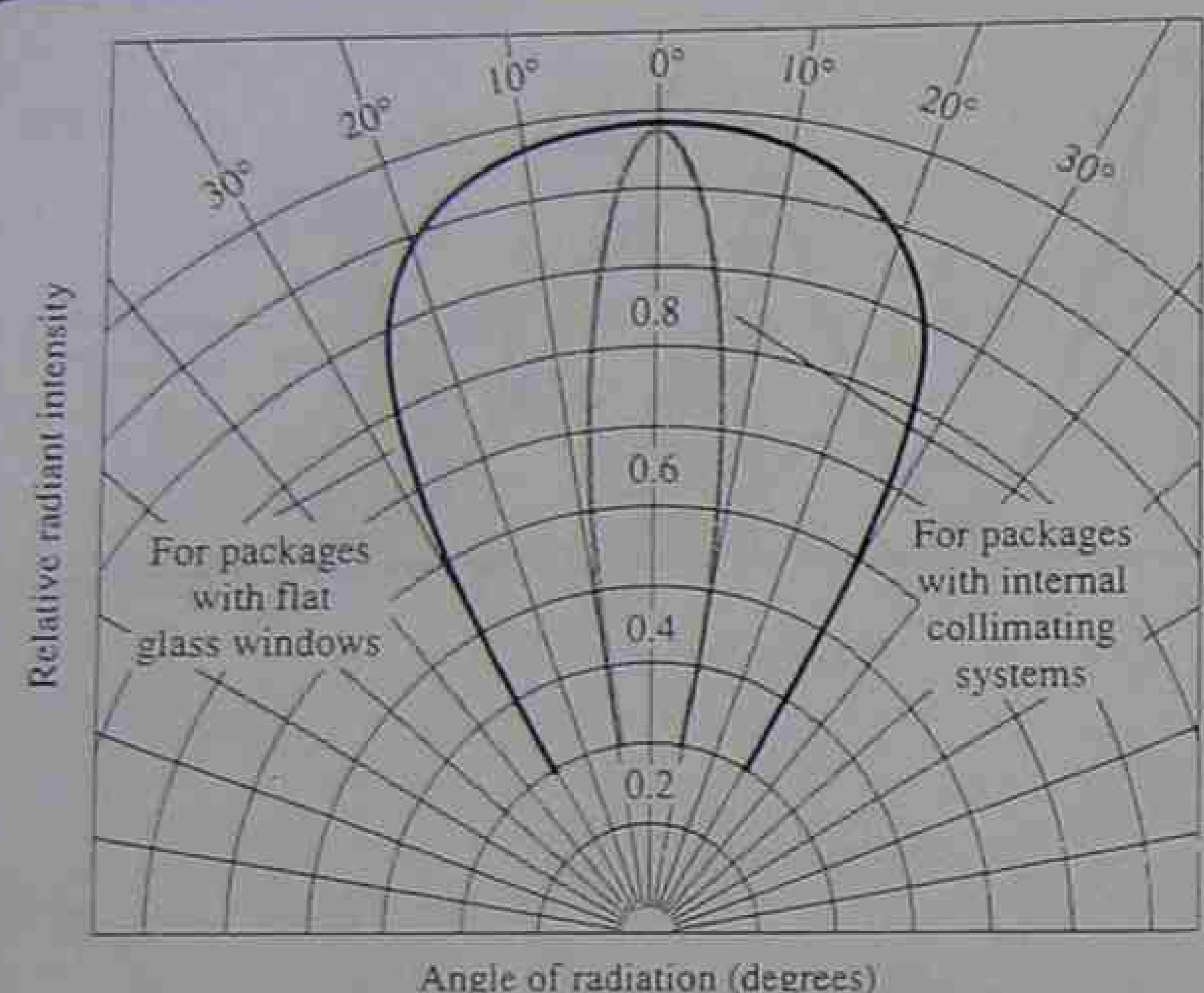
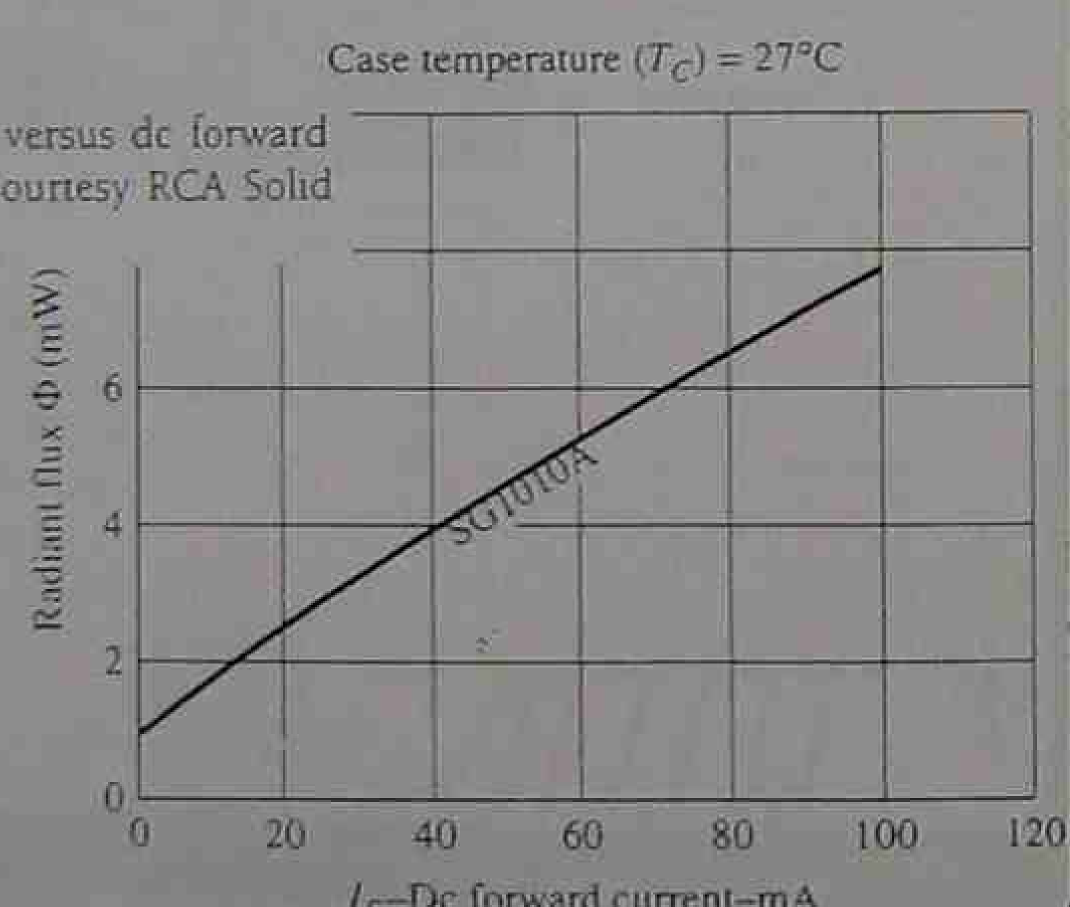


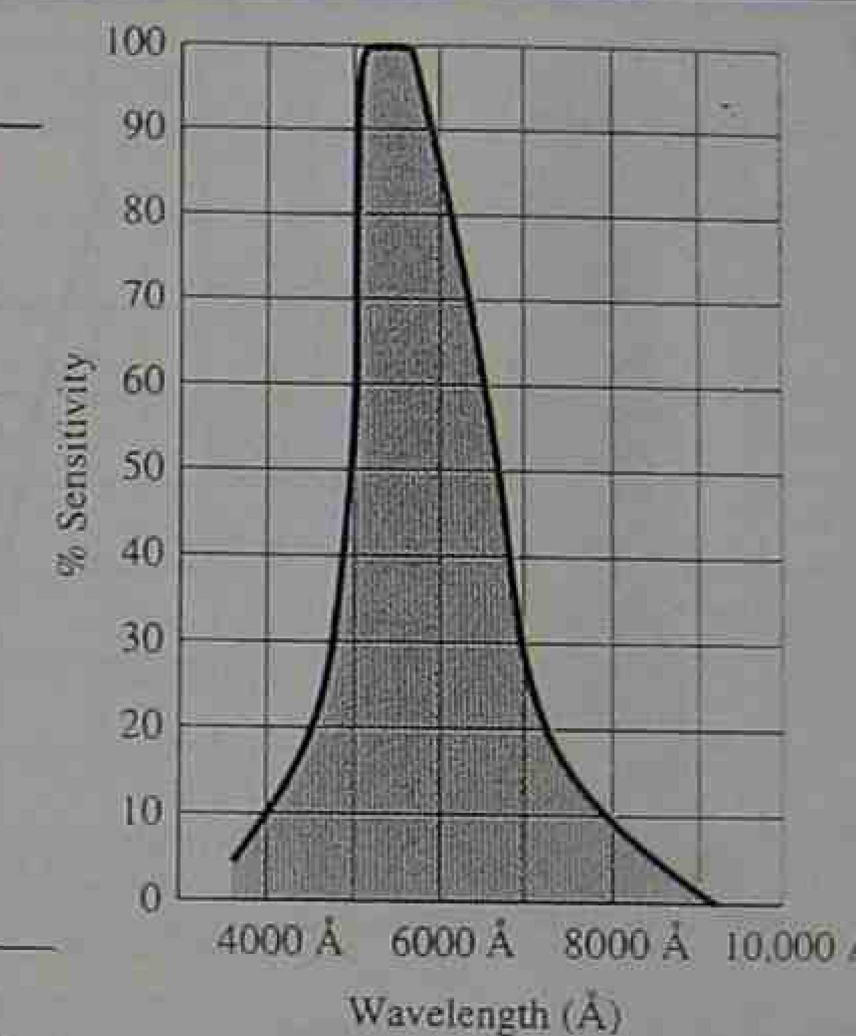
Figure 20.33 Typical radiant intensity patterns of RCA IR-emitting diodes. (Courtesy RCA Solid State Division.)

Figure 20.32 Typical radiant flux versus dc forward current for an IR-emitting diode. (Courtesy RCA Solid State Division.)



Industrial Sensors.

Topic - LED IR EMITTER



Variation of Conductance With Temperature and Light

Footcandles	*.01*	*0.1*	*1.0*	*10*	*100*
Temperature			*% Conductance*		
−25°C	103	104	104	102	106
0	98	102	102	100	103
25°C	100	100	100	100	100
50°C	98	102	103	104	99
75°C	90	106	108	109	104

Response Time Versus Light

Footcandles	*0.01*	*0.1*	*1.0*	*10*	*100*
Rise (seconds)	0.5	0.095	0.022	0.005	0.002
Decay (seconds)	0.125	0.021	0.005	0.002	0.001

Figure 20.30 Characteristics of a Clairex CdS photoconductive cell. (Courtesy Clairex Electronics.)

Industrial Sensors.

Topic - PHOTODIODES

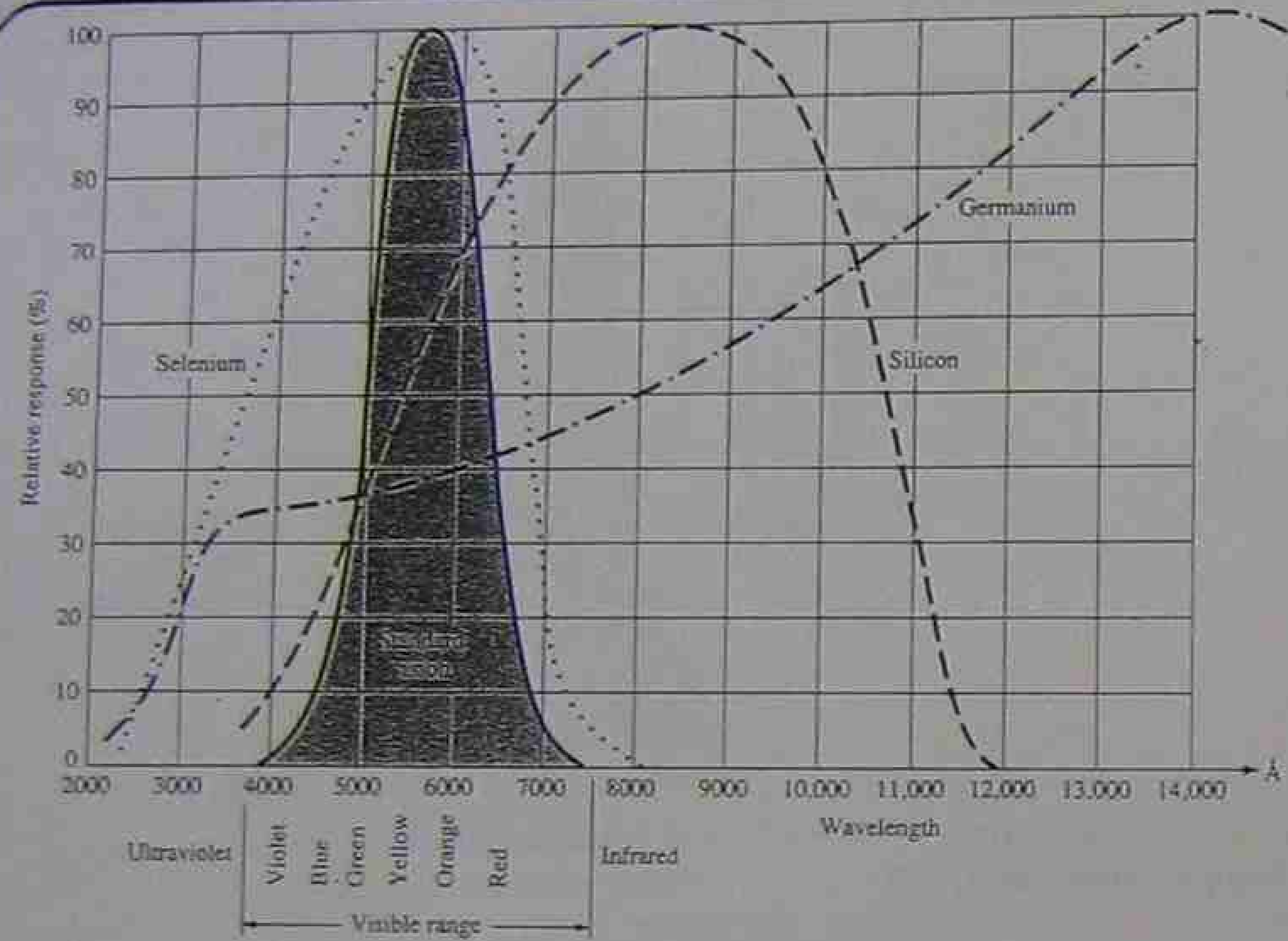
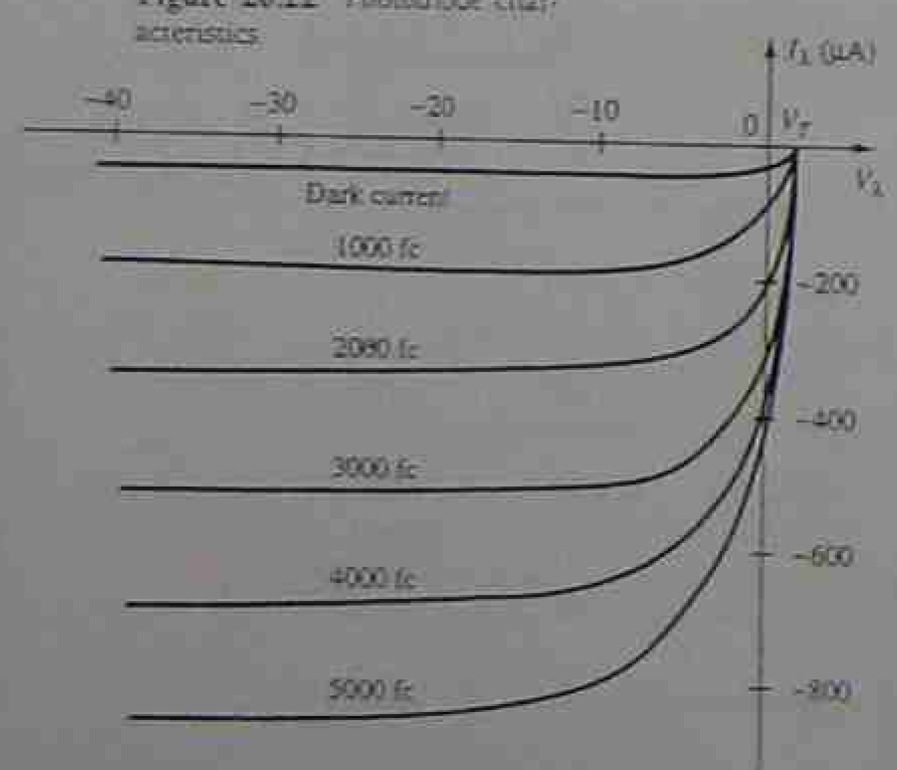


Figure 20.20 Relative spectral response for Si, Ge, and selenium as compared to the human eye.

Figure 20.22 Photodiode characteristics.



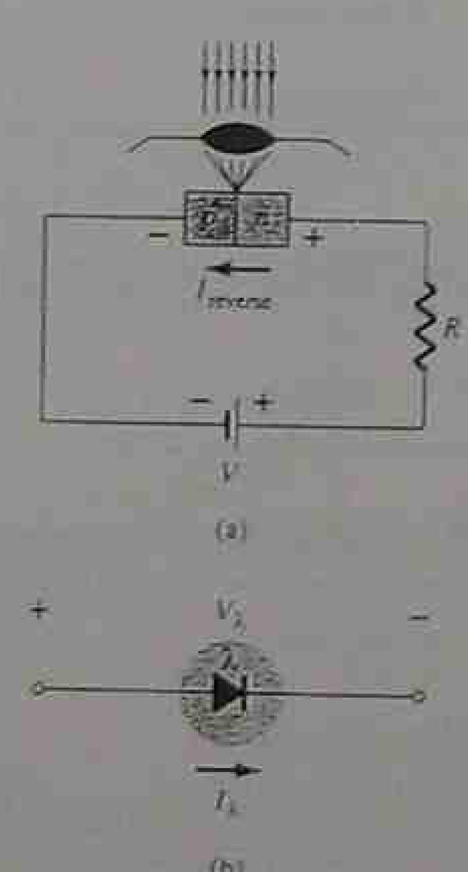
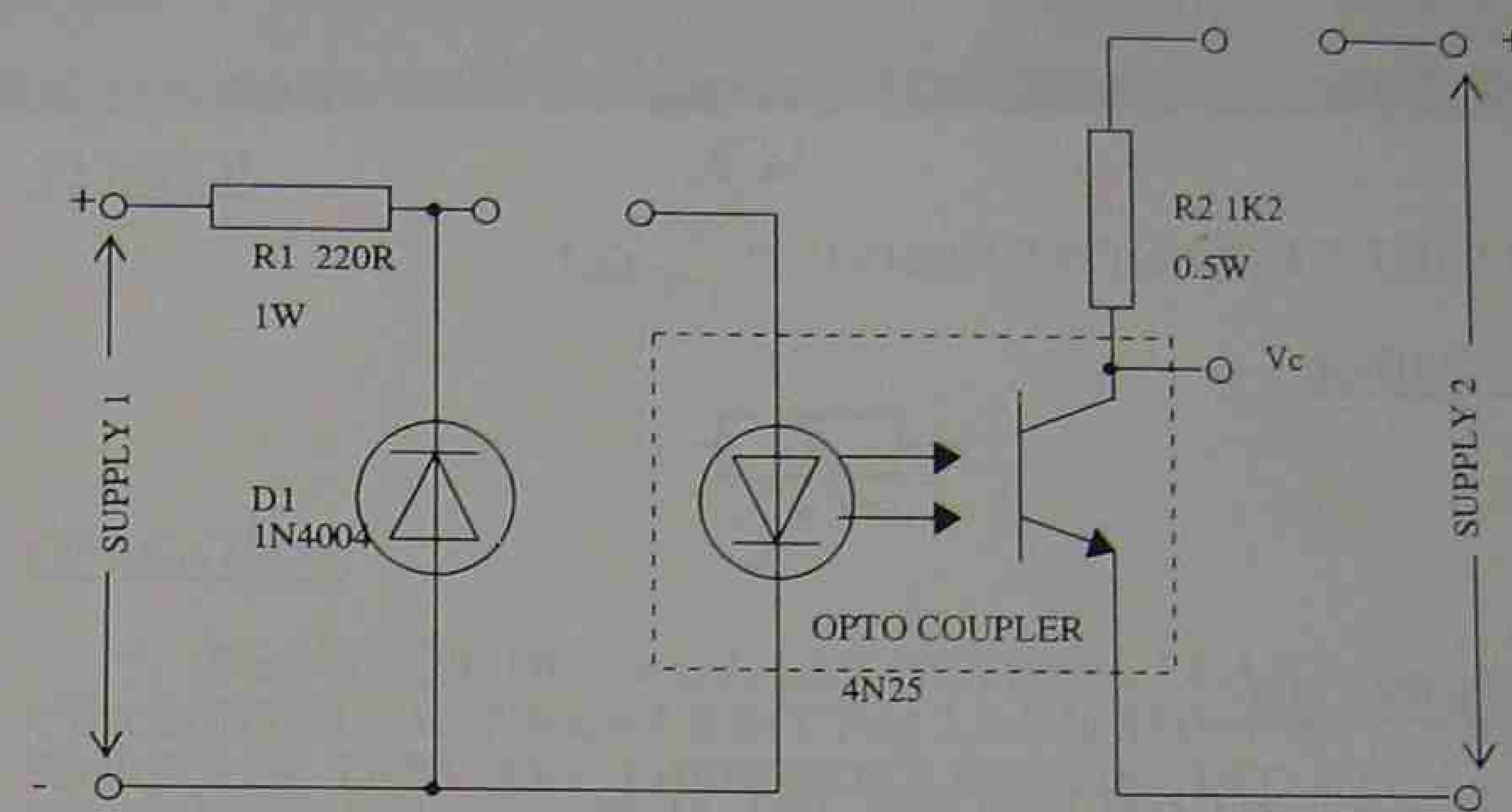


Figure 20.21 Photodiode: (a) basic-biasing arrangement and construction; (b) symbol.



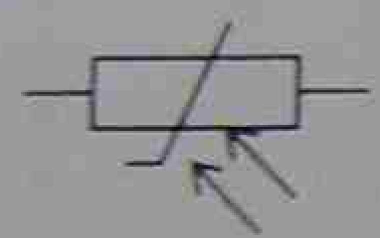
OPTO COUPLER PRACTICAL

Topic - Photoresistor.

LDR

LIGHT DEPENDENT RESISTOR

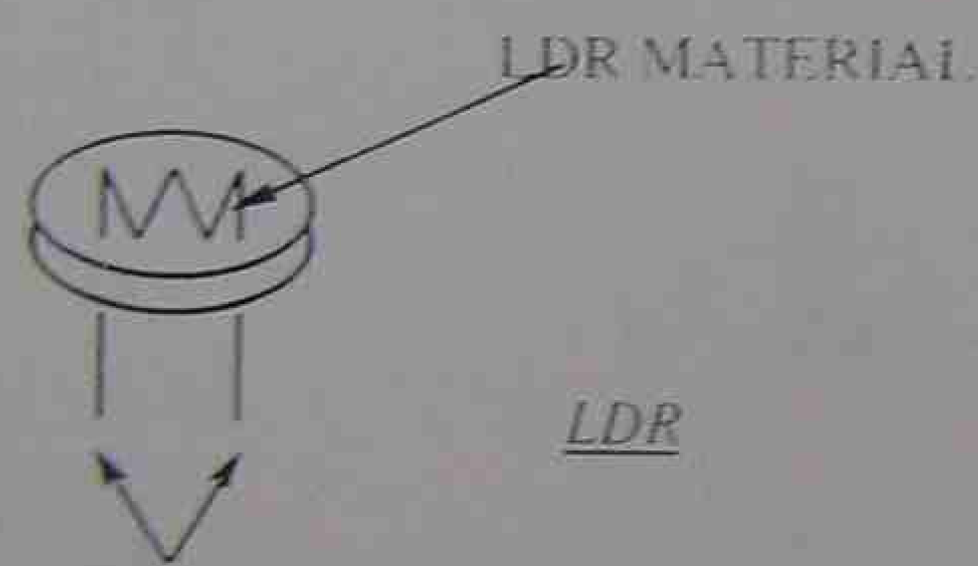
SYMBOL



OPERATION

LIGHT FALLING ON THE SURFACE OF THE LDR CAUSES A DECREASE IN RESISTANCE.

DARK RESISTANCE IS ***VERY HIGH*** AROUND 1M TO 10M.



PEAK SPECTRAL RESPONSE

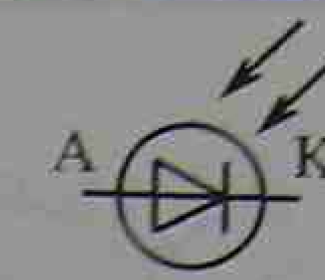
CADMIUM SELENIDE CdS = 735nm(INFRARED)
CADMIUM SULPHIDE CdSe = 530nm to 600nm (EYE)

RESPONSE TIME

VERY SLOW IN SECONDS FROM DARK TO LIGHT

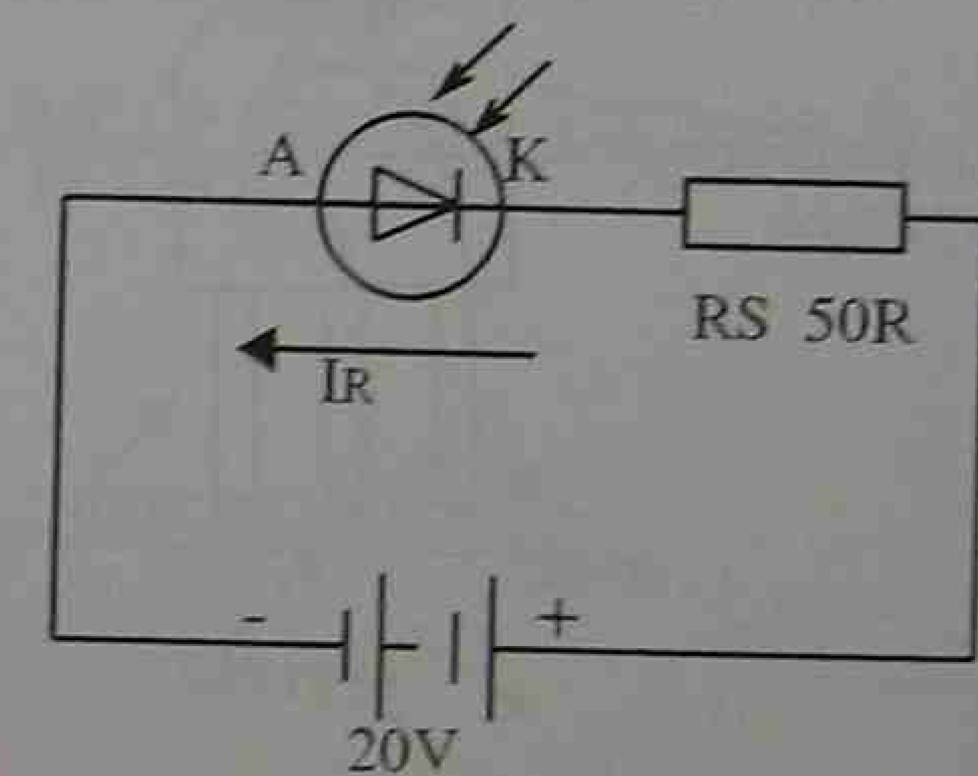
Topic - Photodiode.

SYMBOL



OPERATION

PHOTO DIODES WILL LET REVERSE LEAKAGE CURRENT FLOW WHEN LIGHT FALLS ON THE P.N. JUNCTION. THEY ARE THEREFORE CONNECTED IN REVERSE BIAS.



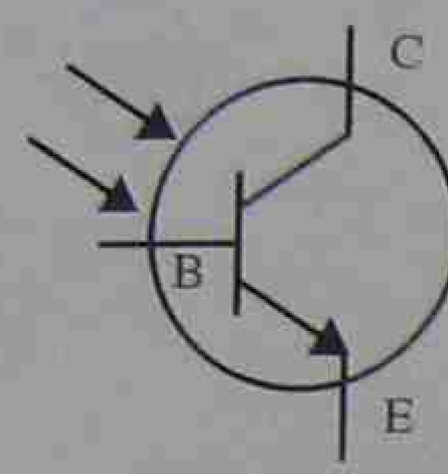
TYPICAL CONNECTION OF PHOTO DIODE

SPECTRAL RESPONSE IS 400nm to 1100nm BUT PEAKING IN INFRARED

RESPONSE TIME IS EXTREMELY FAST = 1nS

Topic - Phototransistor.

SYMBOL



CONSTRUCTION

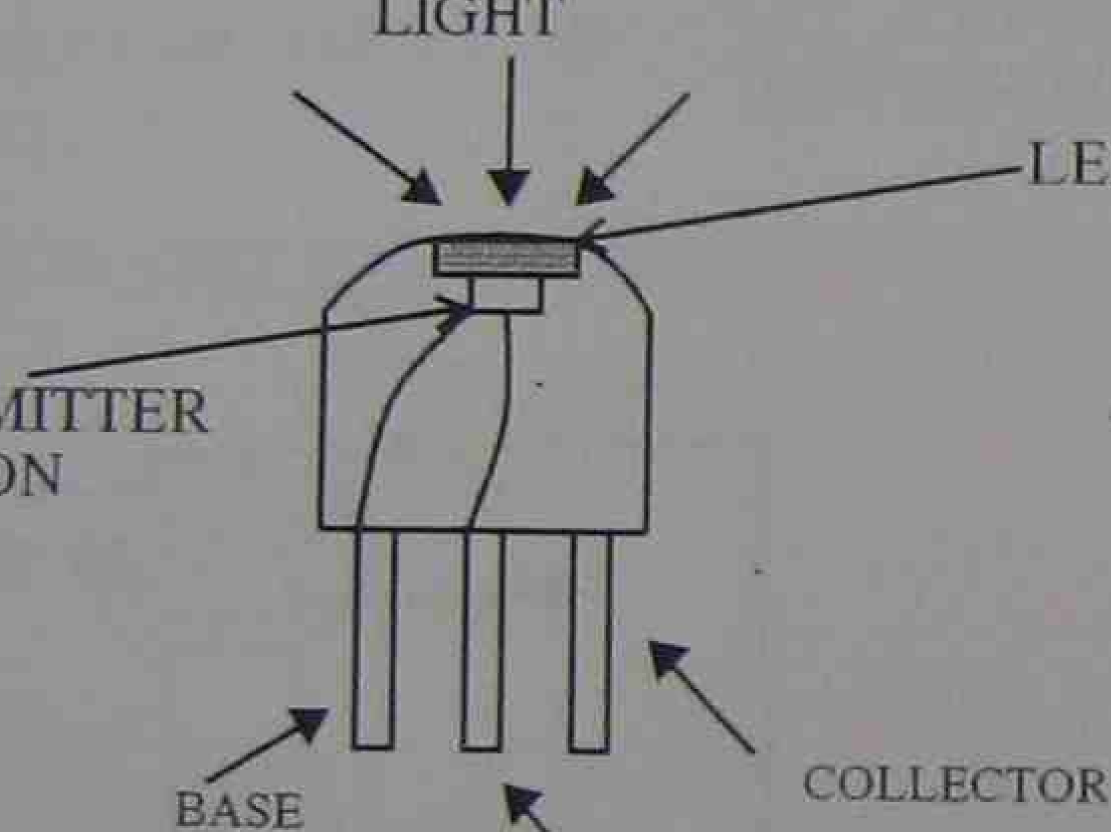


PHOTO TRANSISTOR

OPERATION

LIGHT ENERGY FALLING ON THE BASE / EMITTER JUNCTION CAUSES CURRENT TO FLOW FROM BASE TO EMITTER SWITCHING ON THE TRANSISTOR.

Topic - Phototransistor. (CONT.)

RESPONSE TIME

IS ABOUT 1μS

LENSES ARE USED TO FOCUS AND THEREFORE INCREASE THE LIGHT FALLING ON THE BASE / EMITTER JUNCTION.

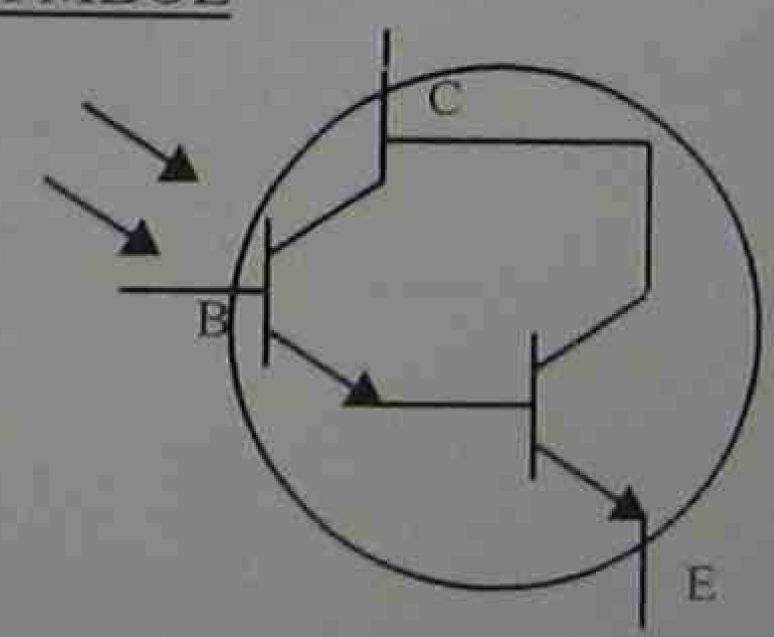
PEAK SPECTRAL RESPONSE IS TO INFRARED ≈900nm

IF THE LIGHT LEVELS TO BE DETECTED ARE VERY LOW A PHOTO DARLINGTON MAY BE USED.
HOWEVER RESPONSE TIME IS REDUCED.

RESPONSE TIME OF PHOTO DARLINGTON

IS ABOUT 75μS

PHOTO DARLINGTON SYMBOL



Topic - Photo SCR -LASCR-.

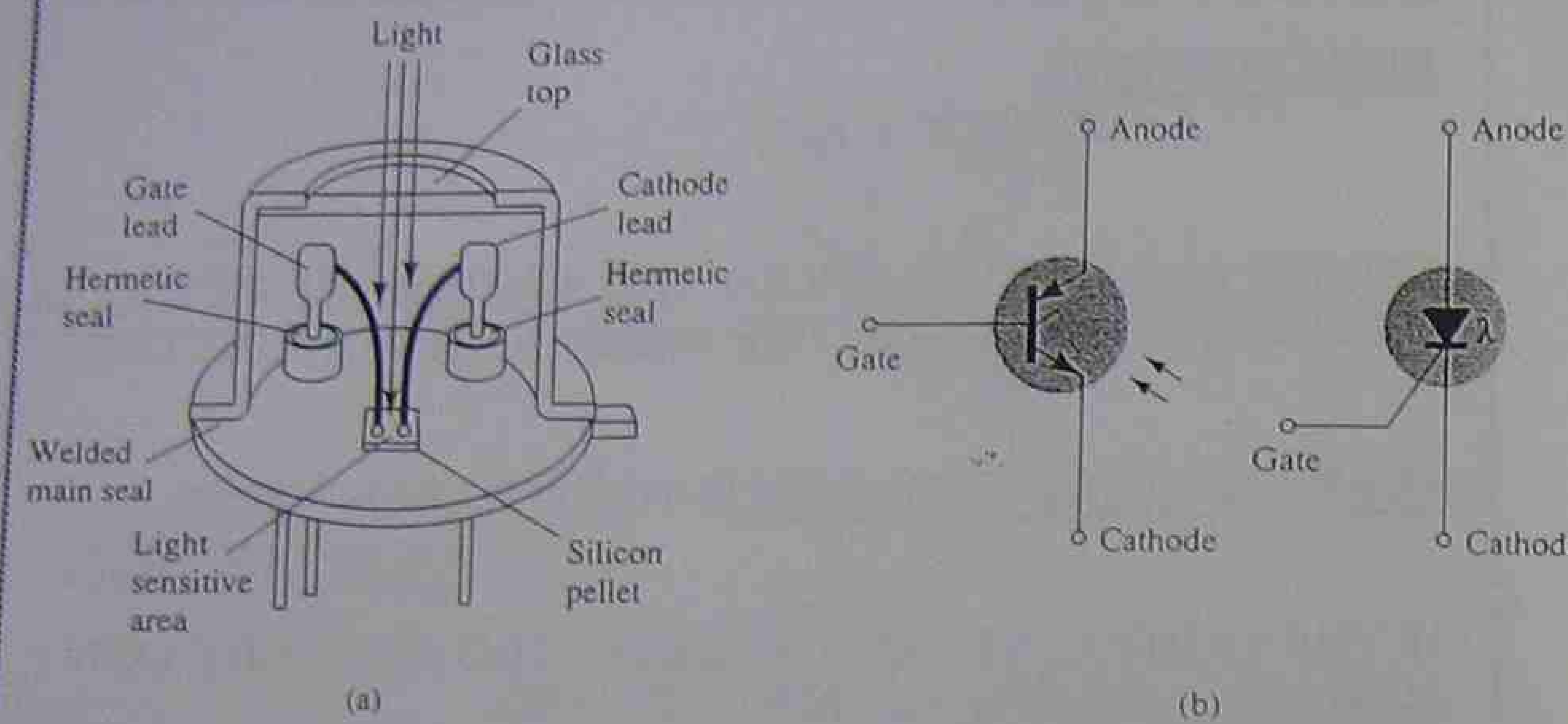
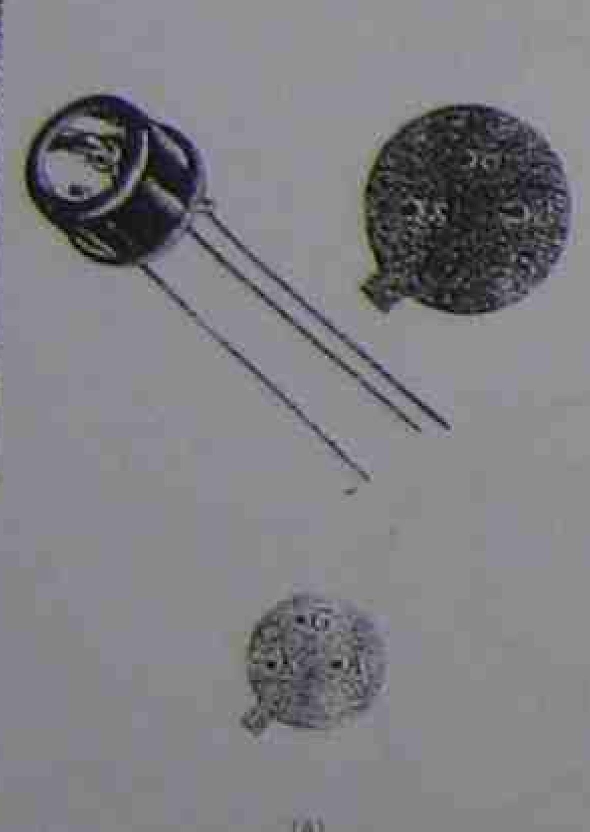


Figure 21.24 Light-activated SCR (LASCR): (a) basic construction; (b) symbols.



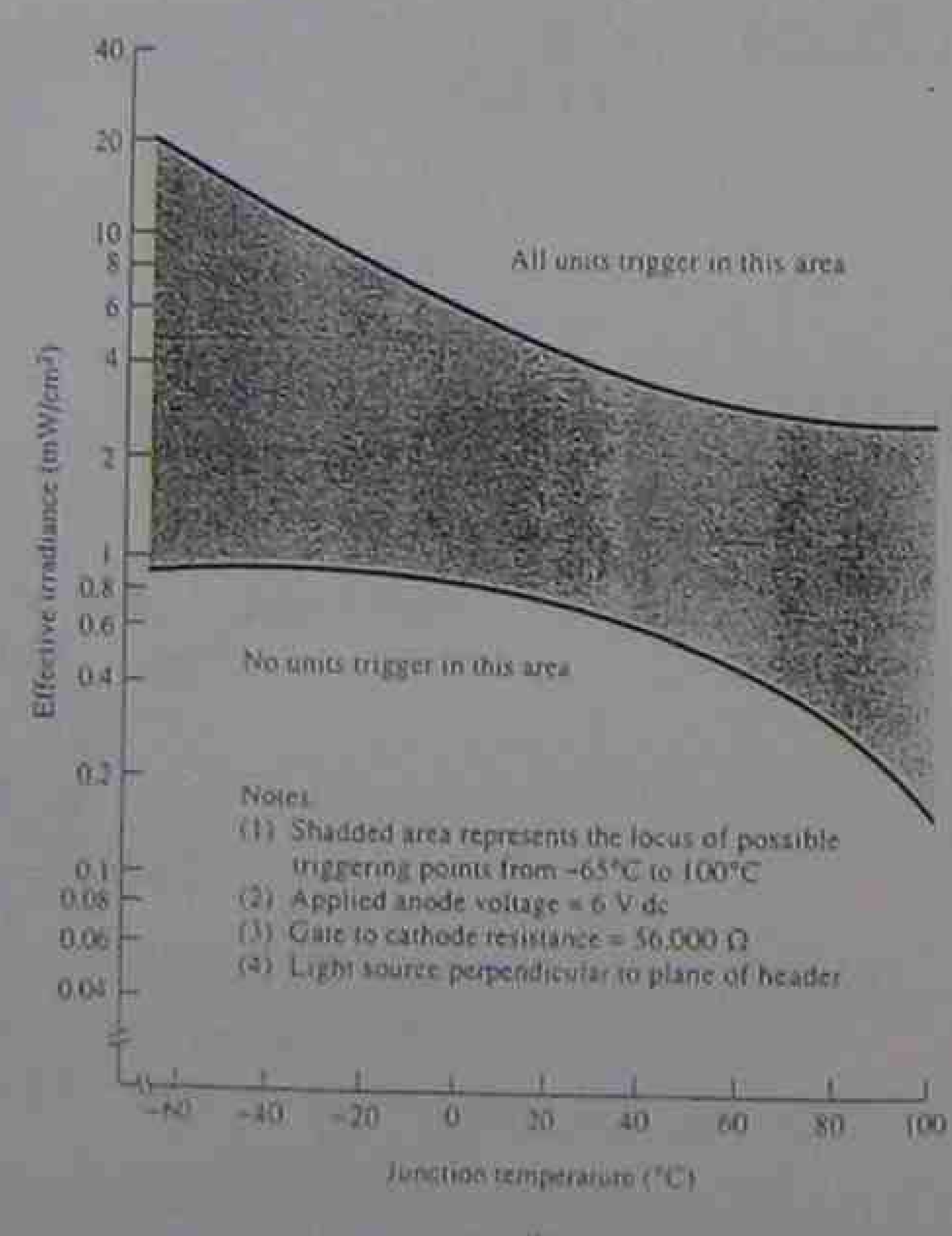


Figure 21.25 LASCR: (a) appearance and terminal identification; (b) light-triggering characteristics. (Courtesy General Electric Company.)

Topic - Photo SCR -LASCR-. (CONT.)

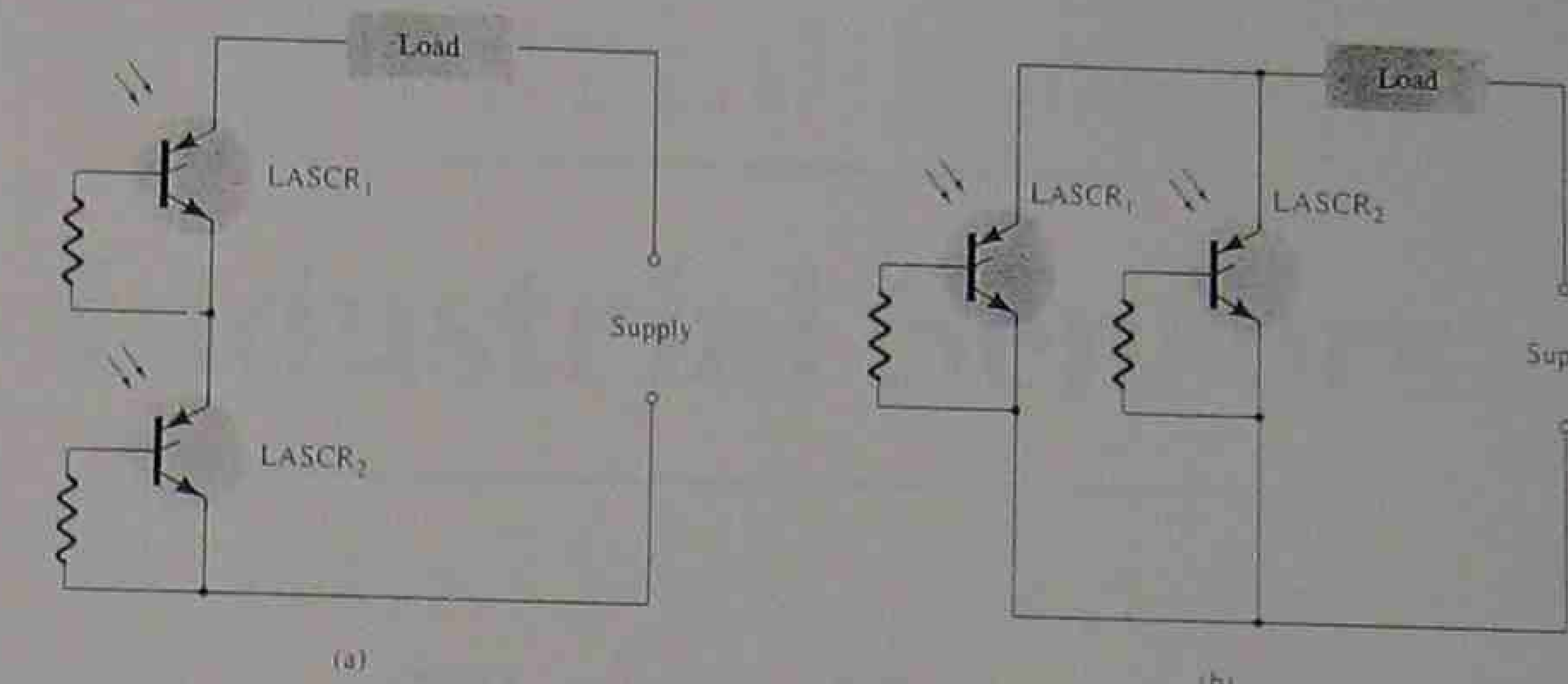


Figure 21.26 LASCR optoelectronic logic circuitry: (a) AND gate: input to $LASCR_1$ *and* $LASCR_2$ required for energization of the load; (b) OR gate: input to either $LASCR_1$ *or* $LASCR_2$ will energize the load.

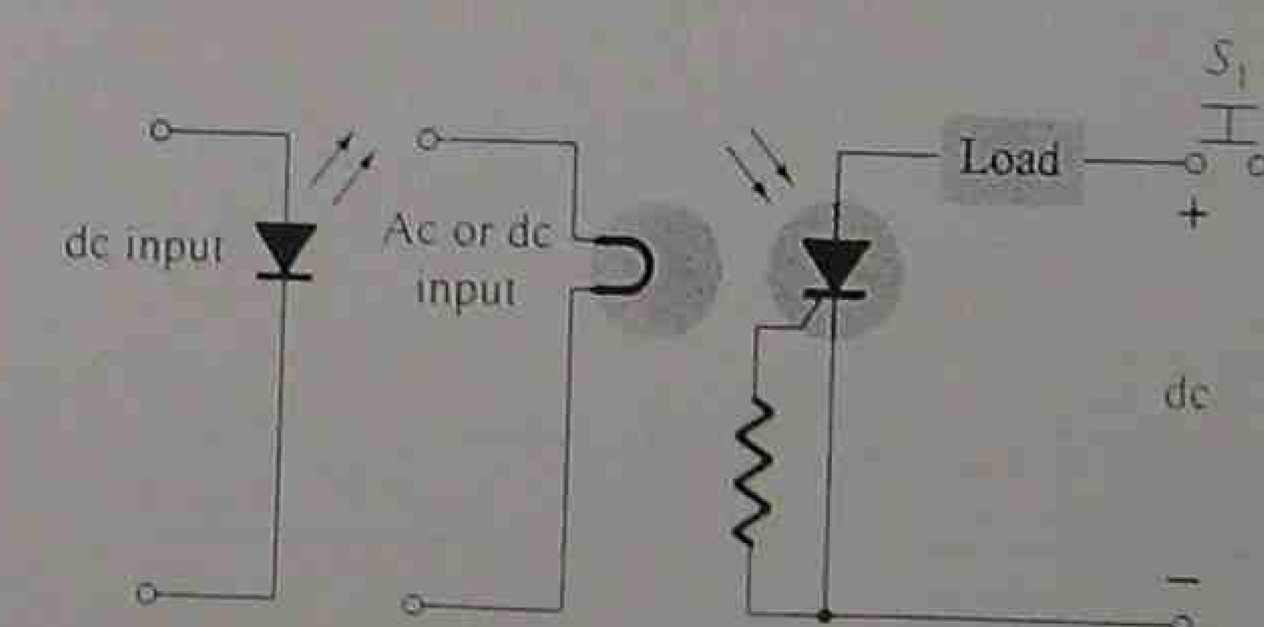


Figure 21.27 Latching relay. (Courtesy Powerex Inc.)

Sydney Institute of Technology

School of Electrotechnology

Industrial Sensors

Theory Notes

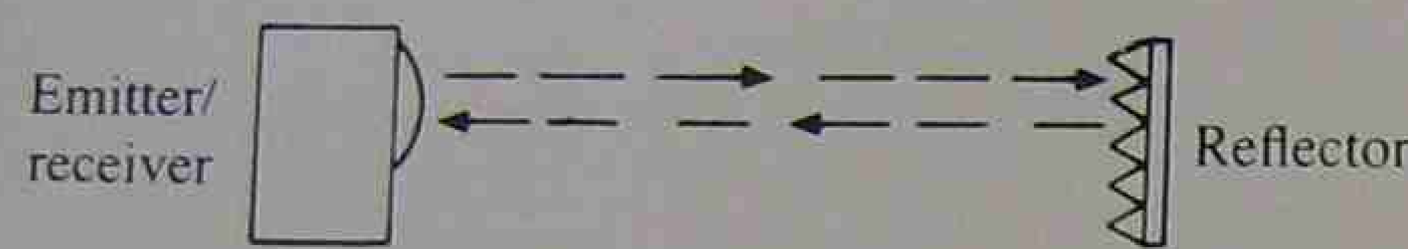
Area ____________________

Topic ____________________

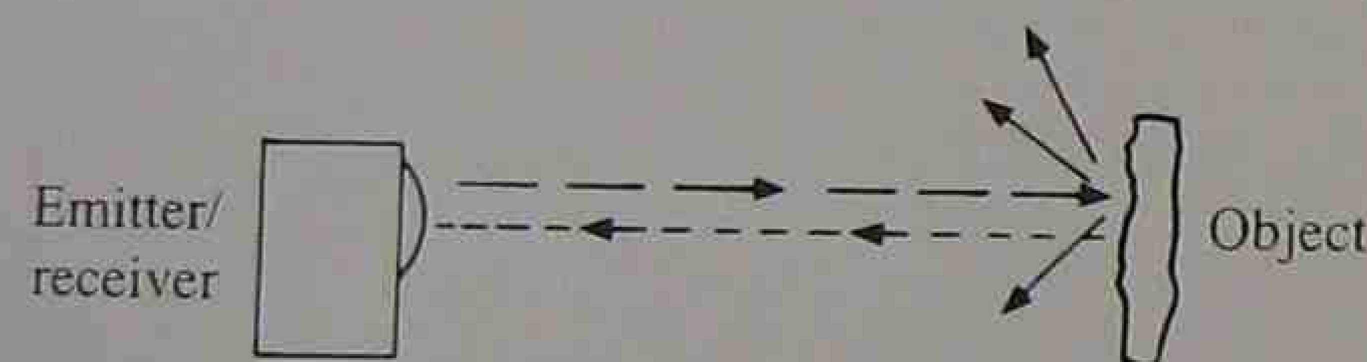
Session No.

For further information on this module, or this subject contact Jim Hafford, (02) 217 3620, Bld. K. Ultimo, S.I.T.

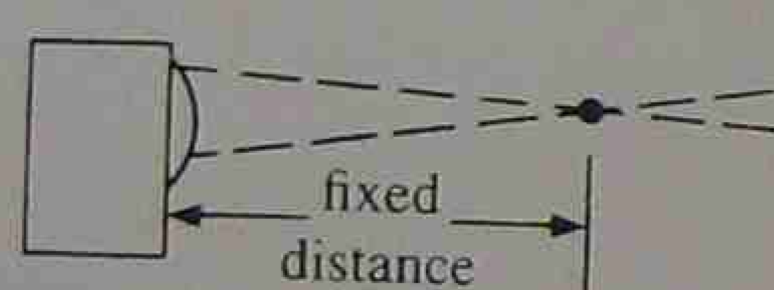
a) Direct scan



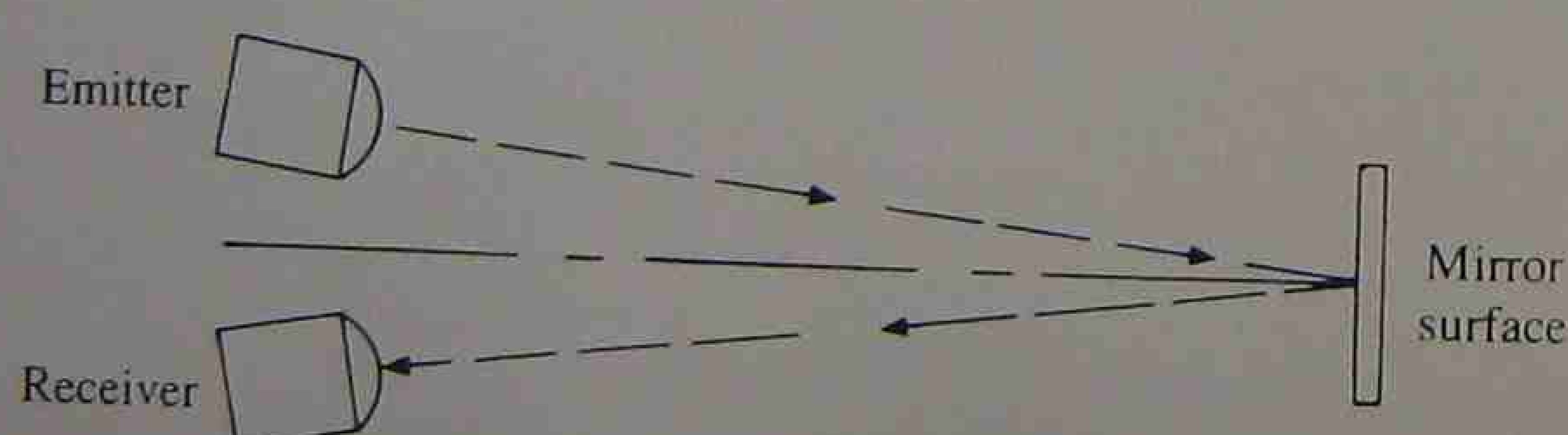
b) Retroreflective scan



c) Diffuse scan



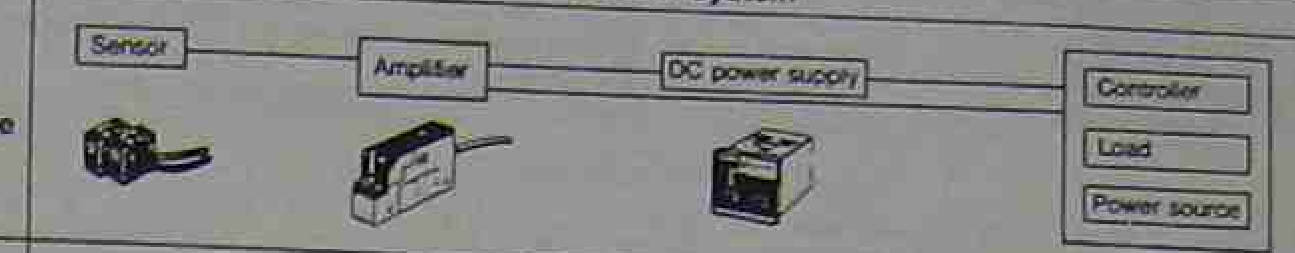
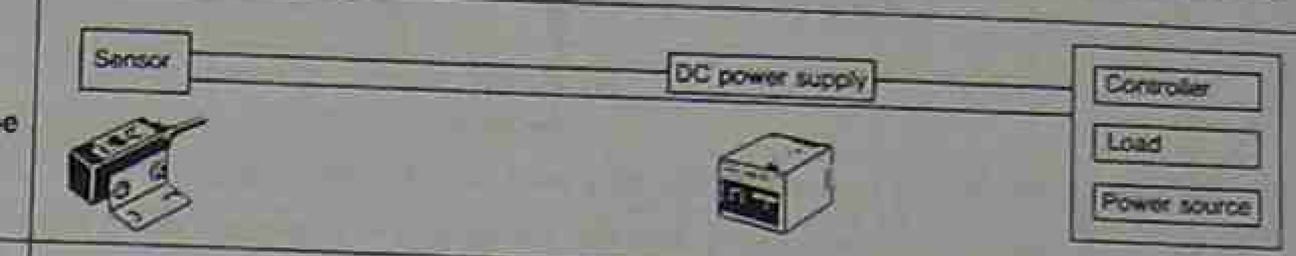
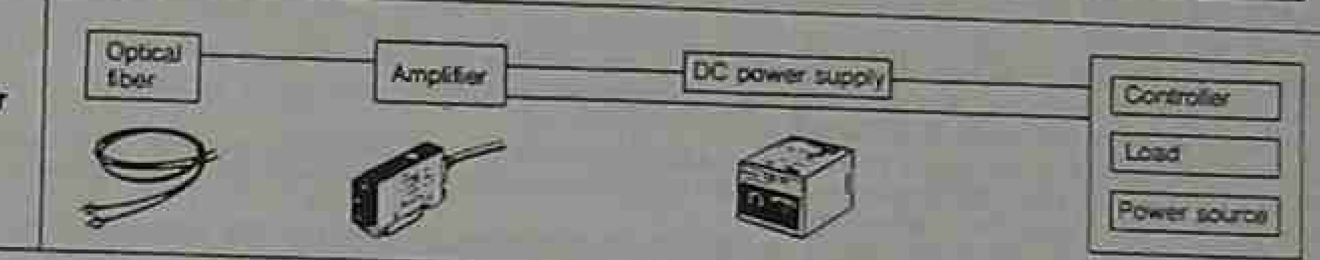
d) Convergent beam scan



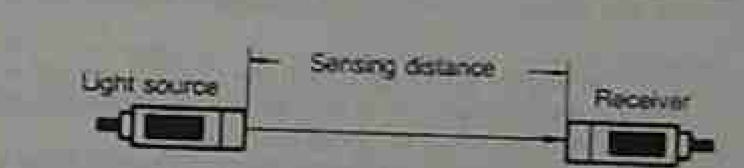
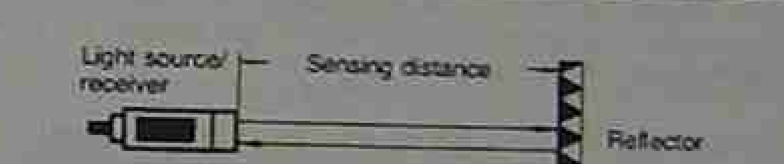
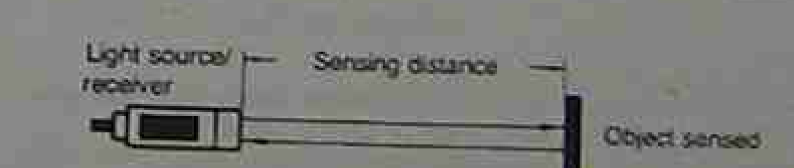
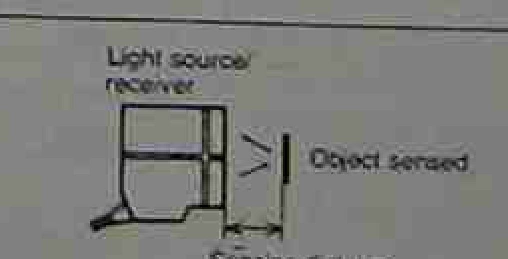
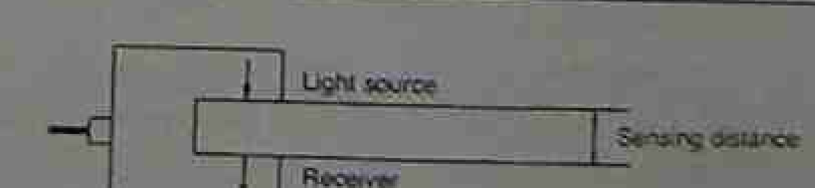
e) Specular scan

GLOSSARY

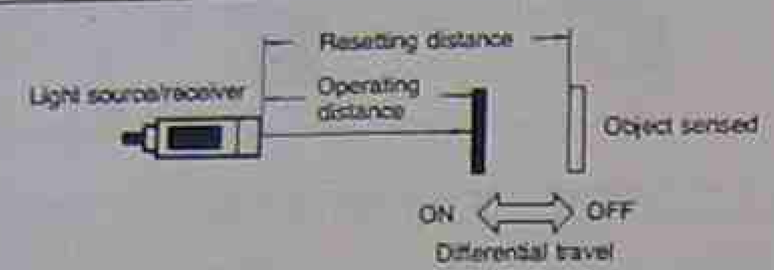
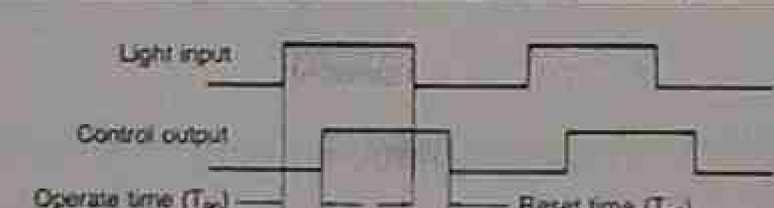
Classification by Product Types

Type	Control system	Features
Separate amplifier type		• Subminiature sensing head • Small mounting space • Remote control of sensitivity possible
Built-in amplifier type		• Operates on DC power • Fast response speed
Built-in power supply type		• Operates on AC power • Easy to handle
Optical fiber type		• Space-saving • Senses very tiny objects

Classification by Sensing Methods

Method	Definition
Separate type	
Retroreflective type	
Diffuse reflective type	
Definite reflective type (focusable reflective type)	
Grooved head type	

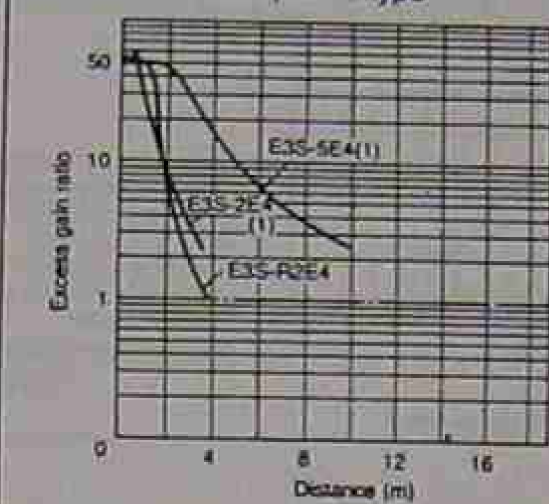
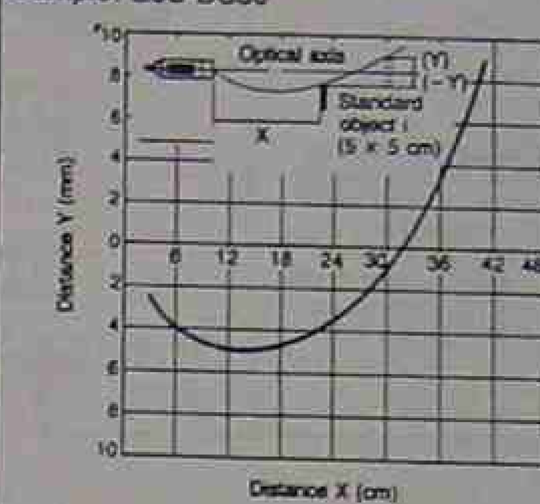
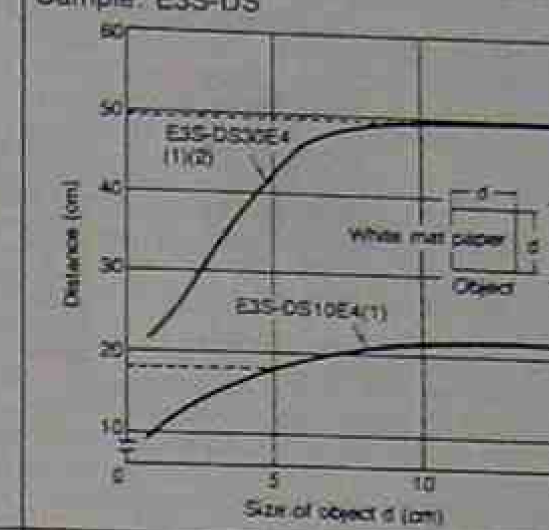
Specifications

Term	Definition
Sensing distance	The term "sensing distance" generally refers to the range within which the photoelectric switch can sense an object. With the separate and retroreflective types, it denotes the maximum distance within which the photoelectric switch can be stably set. With the diffuse and definite reflective types, it denotes the maximum distance within which the photoelectric switch can stably operate with a standard object. The item "sensing distance" under "Specifications" indicates the respective value for each type.
Differential travel	 The differential travel is the distance between the operating point when the object approaches the photoelectric switch and the release point when the object moves away. The item "differential travel" under "Specifications" indicates the value(s) for a standard object and is expressed as a percentage of the sensing distance.
Standard object	With the separate and retroreflective types, the term "standard object" refers to a sensing object of the size which can completely screen the lens optical system. It does not refer to the limit of an object size that can be sensed. With the diffuse reflective type, the term refers to a sensing object of the size which satisfies the rated sensing distance.
Control output	The term "control output" denotes the output required to control a load connected to a photoelectric switch. The control output is divided into the relay output, transistor output, and SCR output. 
Alarm output	The alarm output operates when the control output is in an unstable OFF or ON state for more than 100 ms. An unstable state occurs when the amount of light incident upon the receiving element is within 20% of the amount of light needed to change the control output state. The alarm output feature is designed to indicate gradual changes in sensor/reflector position, atmosphere, temperature, or ambient light which can result in an unstable control output. A change occurring in less than the specified time will not trigger the alarm output. This time delay is built into the alarm output circuit and prevents false triggering of the alarm output as the leading and trailing edges of the object to be sensed are detected.
Power indicator	The POWER indicator lights up when the unit receives the proper supply voltage.
Operation indicator	The OPERATION indicator lights up when the main output load circuit is energized.
Light indicator	The LIGHT indicator lights up when the light from the light source is incident on the receiver and exceeds the operating level (trigger point) of the sensor. For the separate and retroreflective types, the LIGHT indicator lights up whenever the object is absent. For diffuse reflective types, the LIGHT indicator lights up when the object is present.
Stability indicator	The STABILITY indicator lights up when the control output is in a stable OFF or ON state. A stable state occurs when the light receiving element of the sensor is receiving less than 80% (OFF state) or more than 120% (ON state) of incident light needed to operate the sensor. The control output STABILITY indicator goes off every time the amount of light incident on the receiving element is within 20% of the amount of light needed to change the control output state. The unstable control output condition can occur when the sensor encounters the leading and trailing edges of an object. The condition can also occur when the change in sensor/reflector position, atmosphere (dust contamination), temperature, or ambient light causes the light incident on the receiving element to be near the operating level of the sensor.
Response time	 The term "response time" refers to the delay time between when the light is interrupted or incident and when the control output circuit operates or resets. Operate time (T_{on}) and reset time (T_{off}) are indicated individually. However, for photoelectric switches, these times are usually the same.
Operation mode	See table below. The "DARK-ON" type photoelectric switch operates when the light flux incident into the receiver is interrupted or damped, whereas the "LIGHT-ON" type photoelectric switch operates when the light flux incident into the receiver is increased.

	Separate and retroreflective types	Diffuse reflective type
Operates when light is interrupted (DARK-ON)	With object to be sensed — Operates	Without object to be sensed — Operates
Operates when light is incident (LIGHT-ON)	Without object to be sensed — Operates	With object to be sensed — Operates

Engineering Data

Under the title "Engineering Data" in the data sheet of a photoelectric switch, various charts are presented to show the characteristics of the photoelectric switches. Of those charts, the following three are the most important and common.

Receiver output vs. set distance characteristics	Operating area characteristics	Sensing distance vs. size of object
Sample: E3S-5 separate type 	Sample: E3S-DS30 	Sample: E3S-DS 
This chart indicates changes in the output produced by the receiver of a photoelectric switch at various distances by which the receiver is separated from the light source or the sensing head from the object. This curve gives a guideline for determining the distance between the light source and receiver, or between the sensing head and the object. The above example shows the characteristic curve of the Model E3S-5 separate photoelectric switch. Since the sensing distance of E3S-5 is rated at 5 m, the photoelectric switch can, in theory, operate if its rated operating level of about 80 mV is obtained when the light source and receiver are separated 5 m. Actually, however, the receiver output stands at about 700 mV, as the above chart shows, which is about 10 times the rated operating level. Basically, all OMRON photoelectric switches are designed to produce output about three times higher than the rated operating level so that they can operate stably even in adverse environments.	This chart shows the distances between a diffuse reflective photoelectric switch and a standard object to be sensed. The sensitivity of the switch is adjusted to the maximum level and the object moves across the optical axis of the switch. The chart basically indicates the maximum distance between the sensing head and the object at which the switch still operates. In the above example, this distance is about 42 cm.	This chart shows the relation between changes in the sensing distance of a diffuse reflective photoelectric switch and the size of an object. The sensing distance of a photoelectric switch, especially a diffuse reflective type, varies depending on the reflection factor of the surface of an object, which is mainly determined by the object's size. That is, the larger the object, the longer the sensing distance. This chart, therefore, indicates the maximum sensing distance of a switch when the switch is detecting objects of various size. For measurement, a white mat paper is used as the object.

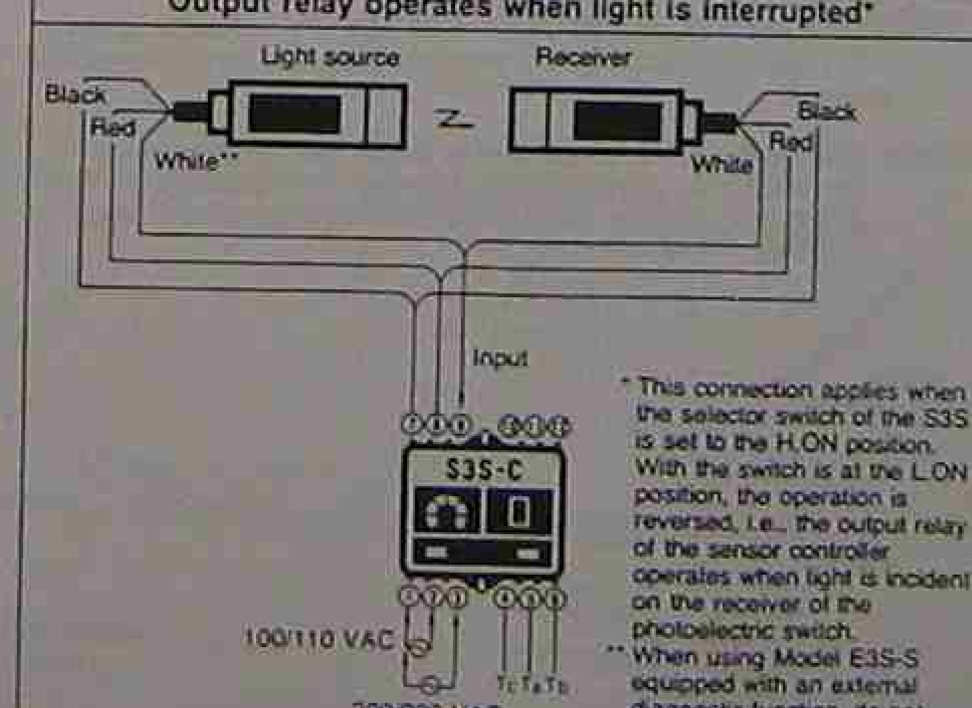
HINTS ON INSTALLATION

Connection

A photoelectric switch is usually used in connection with a control unit such as a Model S3D Sensor Controller or a S3S Control Unit. The following figures illustrate how each type of photoelectric switch should be connected to a controller unit.

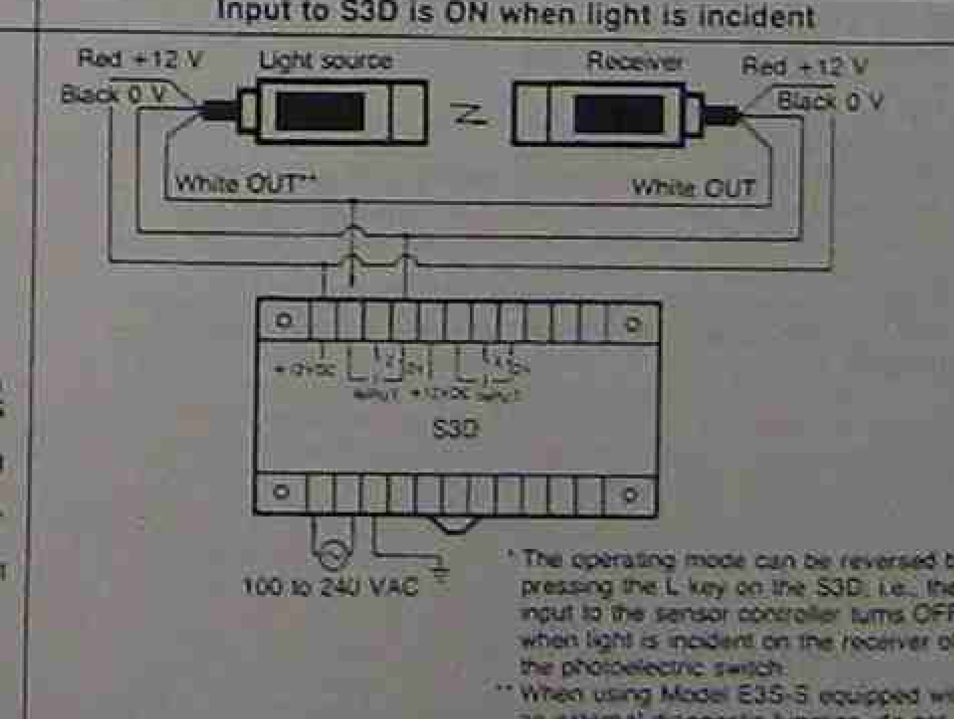
Separate type with solid-state output
(E3S, E3S-X, E3N, E3H, E3F, E3L, E3HF, E3HS, E3HT, E3HC, E3XR)

Output relay operates when light is interrupted*



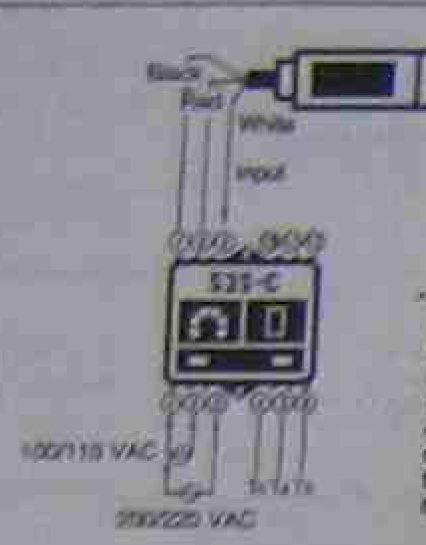
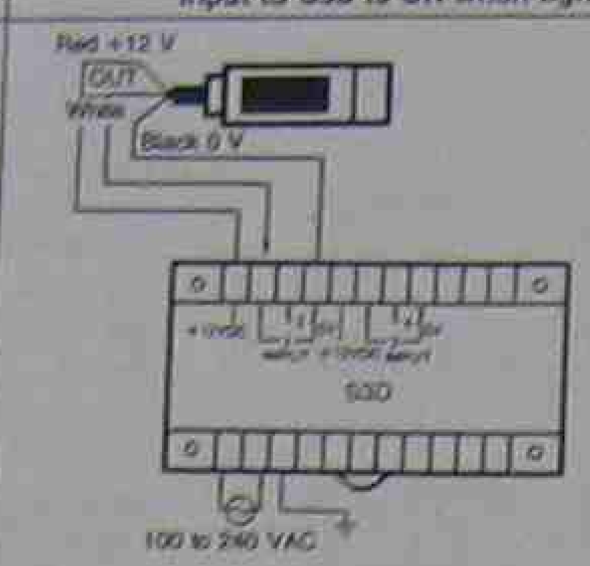
* This connection applies when the selector switch of the S3S is set to the H.ON position. With the switch is at the L.ON position, the operation is reversed, i.e., the output relay of the sensor controller operates when light is incident on the receiver of the photoelectric switch.
** When using Model E3S-S equipped with an external diagnostic function, do not connect the white lead.

Input to S3D is ON when light is incident



* The operating mode can be reversed by pressing the L key on the S3D, i.e., the input to the sensor controller turns OFF when light is incident on the receiver of the photoelectric switch.
** When using Model E3S-S equipped with an external diagnostic function, do not connect the white lead.

Retroreflective, diffuse reflective, and grooved head types with solid-state output (E3S, E3S-X, E3N, E3H, E3F)

Output relay operates when light is interrupted*	Input to S3D is ON when light is incident
 * This connection applies when the selector switch of the S3S is set to the H.ON position. With the switch is at the L.ON position, the operation is reversed, i.e., the output relay of the sensor controller operates when light is incident on the receiver of the photoelectric switch.	 * The operation mode can be reversed by pressing the L key on S3D, i.e., the input to the sensor controller turns OFF when the light is incident on the receiver of the photoelectric switch.

Adjustment

Optical Axis Adjustment
Separate Types

1. Ensure that energizing the output load circuit will not result in injury or damage.
2. Set the operating mode to LIGHT-ON.
3. Using the aiming guide located on the sensing head, move either the light source unit or the receiver unit vertically or horizontally to find a range in which the LIGHT indicator lights up.
4. Position and secure the light source and receiver units in the center of this range.

Sensitivity Adjustment
Retroreflective Types

The following adjustment procedure applies to DARK-ON operation:

1. Ensure that energizing the output load circuit will not result in injury or damage.
2. Set the operating mode to DARK-ON and set the sensitivity adjuster, if provided, to the minimum position (fully counterclockwise).
3. Place the object to be sensed between the sensor and reflector in desired position.
4. Increase sensitivity until the LIGHT indicator lights.
5. Remove the object and confirm that the LIGHT indicator goes off.
6. If the sensor is equipped with a STABILITY indicator (green LED), confirm that it lights when the object is both absent and present.

Diffuse Reflective Types

The performance of the sensor varies with the surface condition of the object to be sensed. Adjustment of the distance and angle of the sensing head may be necessary to obtain optimum performance. The following adjustment procedure applies to LIGHT-ON operation:

Without a Background Object

1. Ensure that energizing the output load circuit will not result in injury or damage.
2. Set the operating mode to LIGHT-ON and set the sensitivity adjuster to the minimum position.
3. Place the object to be sensed in the desired position.
4. Increase the sensitivity until the LIGHT indicator lights up.
5. Remove the object and confirm that the LIGHT indicator goes off.
6. If the sensor is equipped with a STABILITY indicator (green LED), confirm that it lights when the object is both absent and present.

Retroreflective Types

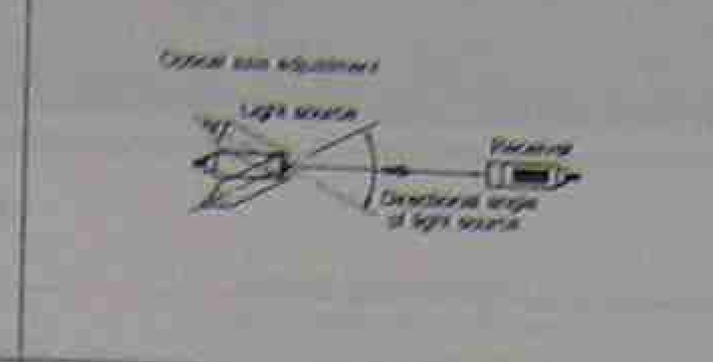
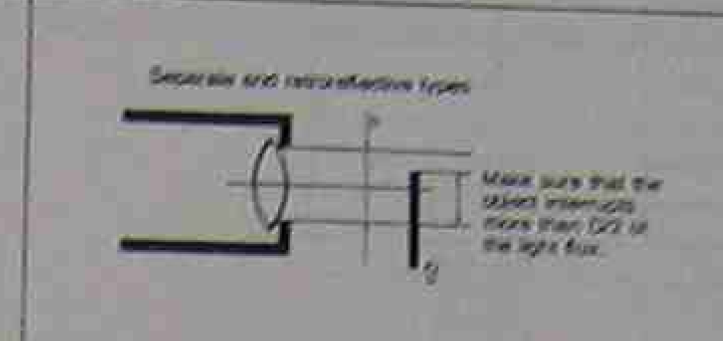
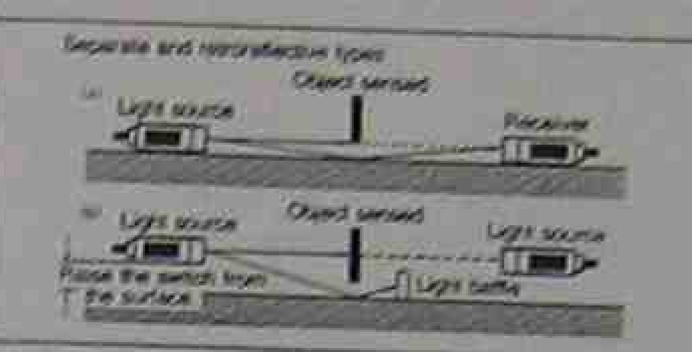
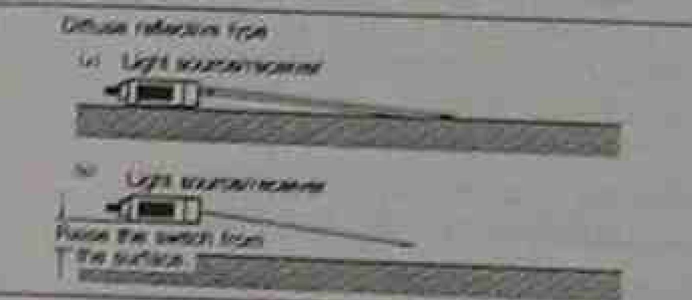
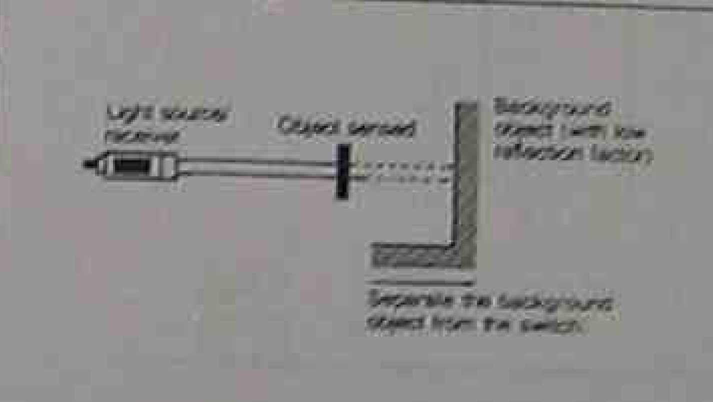
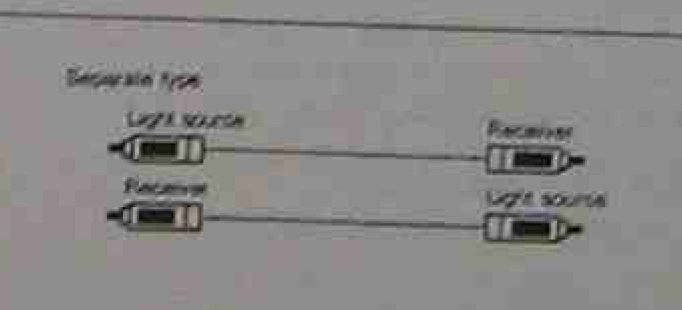
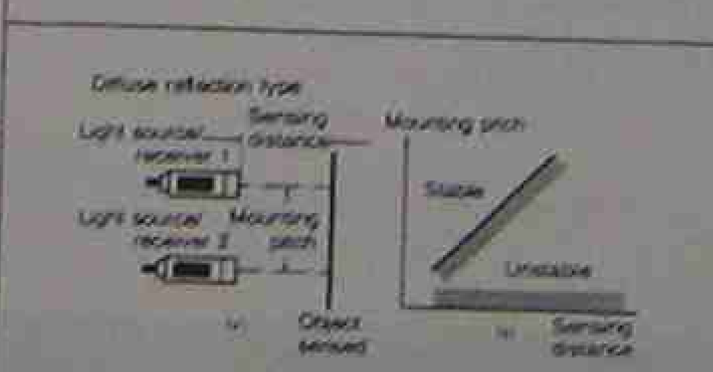
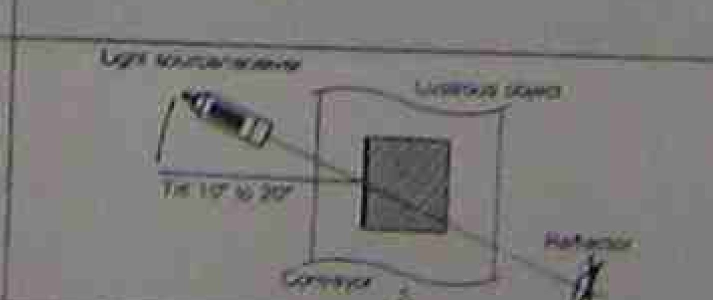
1. Ensure that energizing the output load circuit will not result in injury or damage.
2. Set the operating mode to LIGHT-ON and, if the sensitivity adjuster is provided, set it to the maximum position.
3. Move either the sensor or reflector vertically or horizontally to find a range in which the LIGHT indicator lights up.
4. Position and secure the sensor and reflector in the center of this range.

With a Background Object

1. Keep the background object as far away as possible from the sensor, or make sure that the background object has a black, non-glossy surface with a low reflection factor.
2. Ensure that energizing the output load circuit will not result in injury or damage.
3. Set the operating mode to LIGHT-ON and set the sensitivity adjuster to the minimum position (fully counterclockwise).
4. Place the object to be sensed in the desired position.
5. Increase the sensitivity until the LIGHT indicator lights up. Note the position of the sensitivity adjuster.
6. Remove the object and confirm that the LIGHT indicator goes off.
7. Increase the sensitivity until the background object is sensed, as indicated by the LIGHT indicator, or until the maximum sensitivity is reached.
8. If the background object was sensed, decrease the sensitivity until the LIGHT indicator goes off. Note the position of the sensitivity adjuster.
9. Set the sensitivity adjuster midway between where the object was sensed (step 5) and where the LIGHT indicator goes off (step 8). If the background object was not sensed, the sensitivity adjuster should be set midway between where the object was sensed (step 5) and the maximum sensitivity position (step 7).
10. If the sensor is equipped with a STABILITY indicator (green LED), confirm that it lights when the object is both absent and present.

Note: Follow the same procedure to adjust the sensitivity when the sensor is used for mark sensing. In this case, mark sheet and register mark correspond to background and sensing object.

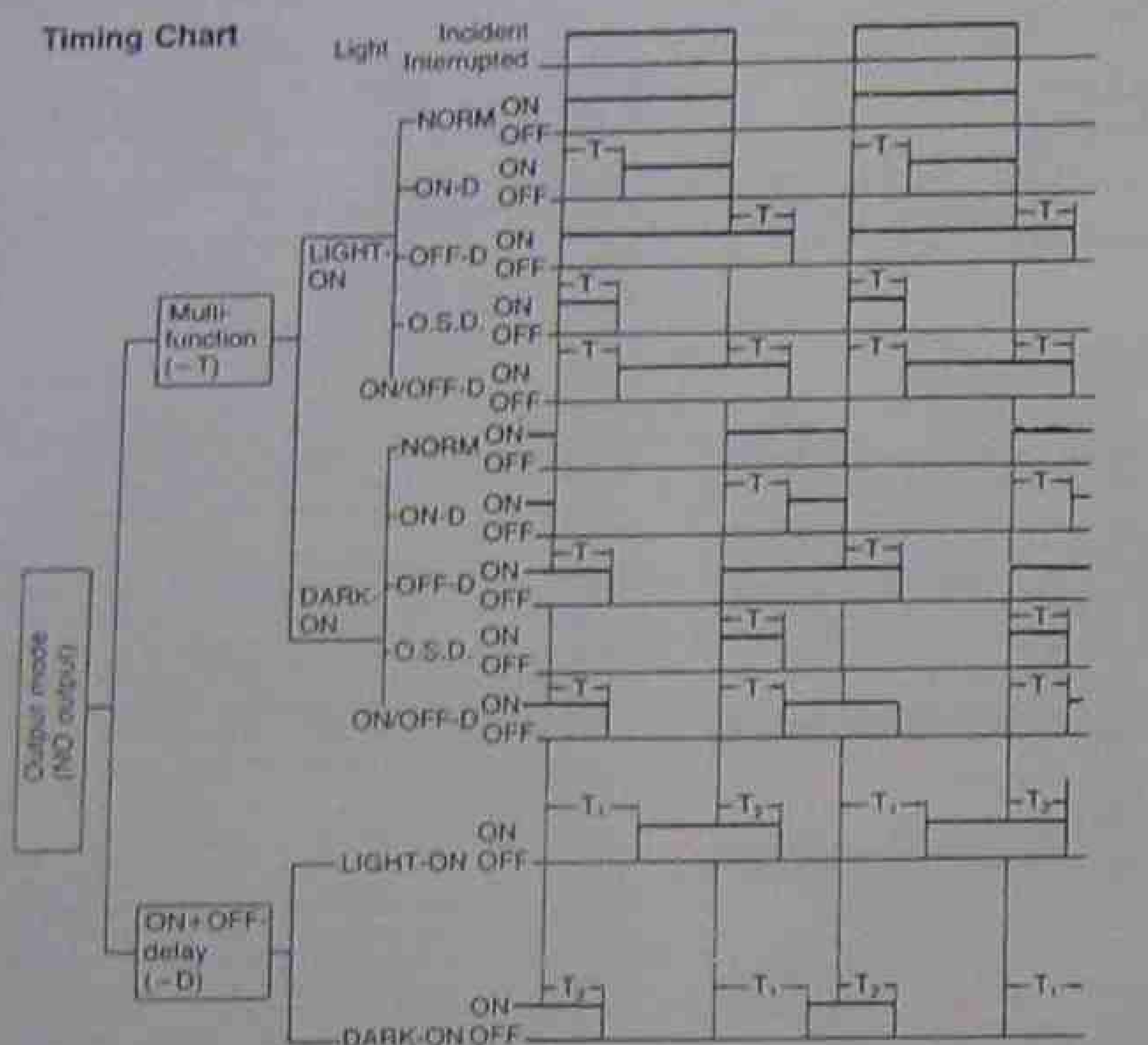
Mounting

Optical axis adjustment and operating level		When the optical axis is adjusted to the optimum position, the operating level of the separate and retroreflective photoelectric switches can be increased up to three times the rated level. With a model equipped with a STABILITY indicator (green LED), adjust the optical axis so that the indicator lights up. Adjust the optical axis by following these steps: 1. Temporarily fix the light source and receiver and roughly adjust the optical axis. 2. Move the receiver horizontally and vertically to find a range within which the indicator lights up. Set and fix the receiver at the center of this range. 3. Adjust the optical axis of the light source in the same manner as the receiver.
Checking for stable operation		To assure stable operation of the separate and retroreflective photoelectric switches, make sure that the object covers at least half the lens surface of the light source or receiver and interrupt the light flux incident on the lens. With a model equipped with a STABILITY indicator (green LED), install the photoelectric switch so that the indicator lights when the light is incident. Note, however, that this is not an absolute rule and the photoelectric switch can be still used even when the indicator does not light, provided that there is little fluctuation in ambient temperature and light, and that the lens surface is clean.
Influence of the mounting surface		When a separate type photoelectric switch is directly installed on a flat (especially smooth) surface, the light flux may be reflected from the surface of the installation surface, as figure (a) shows, affecting the switch operation. In this case, install the switch above the installation surface or provide a light baffle as shown in figure (b). With a model equipped with a STABILITY indicator (green LED), it can be determined whether or not the switch is operating stably when the indicator lights up.
		If a retroreflective photoelectric switch is directly installed on a rough surface, the light flux may be reflected back from the surface to the sensing head, as figure (a) indicates, affecting the switch operation. In this case, install the switch above the surface or change the installation angle. With a model equipped with a STABILITY indicator (green LED), it can be determined whether or not the switch is operating stably when the indicator lights up.
Influence of a background object		If there is a background object behind the object to be sensed, a diffuse reflective photoelectric switch may be affected by the light reflected from a background object. Moreover, if the background object has a high reflection factor, the switch is more likely to be affected. It is therefore recommended to use a definite reflective photoelectric switch if a background object is present. Generally, a black background object does not affect switch operation. If the color of the background object is similar to that of the object to be sensed, make sure that the switch operates stably only when it senses the target object. With a model equipped with a STABILITY indicator (green LED), it can be determined whether or not the switch is operating stably when the indicator lights up.
Mutual interference		When two or more separate type photoelectric switches are installed side by side, the light source of one of the switches may be affected by that of the other, or vice versa. This is called mutual interference. If mutual interference is expected, install the light sources and receivers alternately as shown in the figure, or provide sufficient distance between the switches. Model E3C is provided with mutual interference preventive function and more than one unit of this type can be installed side by side without any special arrangements.
		When two or more diffuse reflective photoelectric switches are installed side by side, mutual interference may also take place. This is because the light emitted from one of the switches may be reflected from the object and incident on the other switch, as figure (a) shows, especially when the surface of the object to be sensed or background object has a high reflection factor. If this happens, either move up the switches closer to the object or provide enough distance between the switches, as shown in (b). Models provided with a mutual interference preventive function can be installed side by side without any special arrangements.
Installation of a reflector		When using a retroreflective photoelectric switch to sense a object with a high reflection factor, install the reflector of the switch, tilting it slightly (to 10° to 20°). To sense cylindrical objects such as pins, tilt the reflector in the vertical direction. The photoelectric switch with a mirror surface rejection function does not have to be tilted.

Industrial Sensors.

Topic -

Timing Chart



ONE SHOT

Note:
1. T_1, T_2, and T denote set time (variable within 0.1 to 5s).
2. T_1 and T_2 are independently variable.
3. Photoelectric switches without timer function have the same function as those with multi-timer function in NORM mode.
4. T_3 LEADING EDGE TRIGGER.
5. T_4 TRAILING EDGE TRIGGER.

Industrial Sensors.

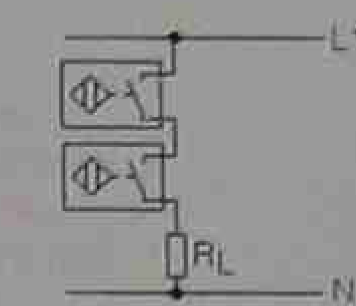
Topic -

2-wire AC (Alternate current)

Principal circuit diagram

Series connection of 2-wire AC-sensors

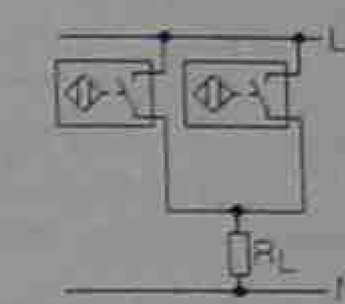
Normally open: AND-configuration
Normally closed: NOR-configuration



When sensors are series connected voltage drops of the individual sensors must be added. This reduces the usable voltage at the load. It should be noted that the voltage drop does not result in a voltage at the load lower than the minimum admissible supply voltage (please consider the main supply fluctuations).

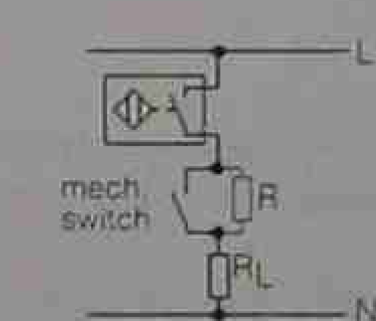
Parallel connection of 2-wire AC-sensors

Normally open: OR-configuration
Normally closed: NAND-configuration



When sensors are parallel connected their leakage currents add. This can result in:
- *simulation of high level on PLC-inputs*
- *passing the holding current of miniature relays and thus preventing drop-out of the relay contacts.*

Series connection of mechanical switches with AC-sensors

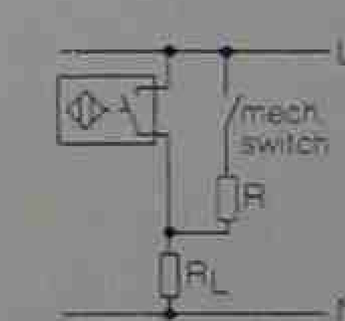


The open contact interrupts the supply voltage of the sensor. If the sensor is damped and the mechanical contact closes a short time delay will occur. The time before availability ($t \leq 80$ ms) of the sensor prevents immediate switching.

Recommendation: *A resistor, parallel to the mechanical contact, supplies the sensor during open contact state, so that the problem of time before availibility does not occur. For 220 VAC the value of the resistance is approximately 82 kΩ / 1 W.*

Calculation of resistance value
400 Ω per Volt

Parallel connection of mechanical switches with AC-sensors



The closed contact shorts the supply voltage of the sensor. After opening the contact the sensor is operational after the time delay before availability ($t \leq 80$ ms).

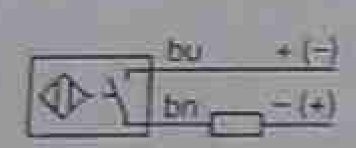
Recommendation: *Resistor in series with the contact ensures that the minimum supply voltage is available for the sensor, thus, the time delay before availability after opening of the mechanical contact is avoided.*
Formula to calculate the resistance value:

$$R = \frac{10\,V}{I_{gad}} \qquad P = I^2_{gad} \times R$$

Industrial Sensors.

Topic -

2-wire DC (Direct current)

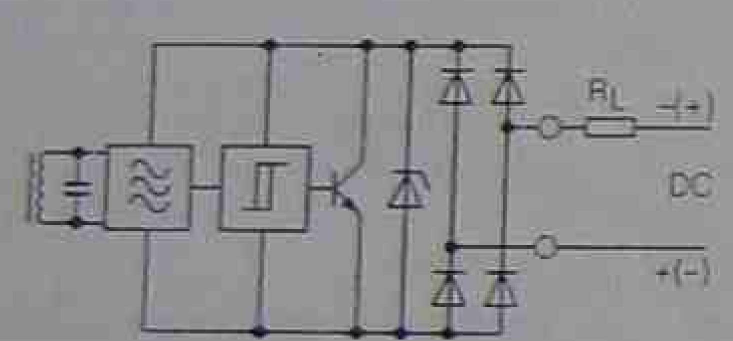


- coding: ...**-AD4-**...

- suitable for use with PLC-systems

- supply voltage: 10...65 VDC
- normally open (NO)
- non-polarized
- short-circuit protected
- leakage current ≤ 0,8 mA
- voltage drop ≤ 5 V

Principal circuit diagram



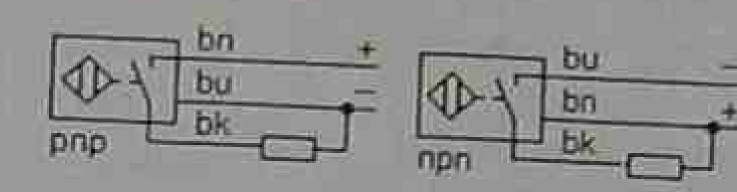
Series- and parallel connection
of 2-wire DC-sensors

• not permitted

Industrial Sensors.

Topic -

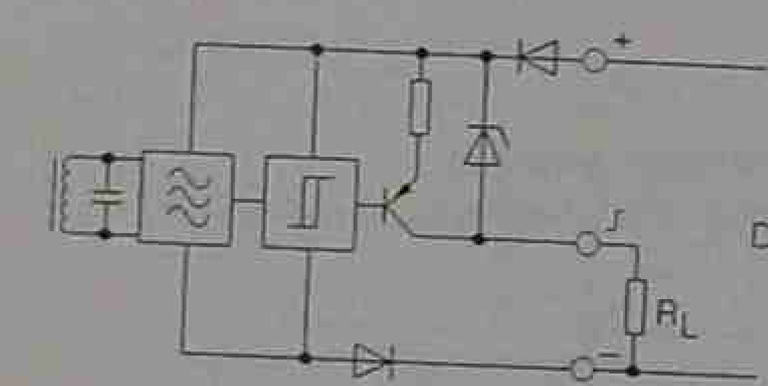
3-wire DC (Direct current)



- coding: ...**-AP6** (pnp)
- coding: ...**-AN6** (npn)

- supply voltage: 10...30 VDC
- normally open (NO)
- voltage drop ≤ 1,8 V
- short-circuit protected output
- complete reverse polarity protected

Principal circuit diagram

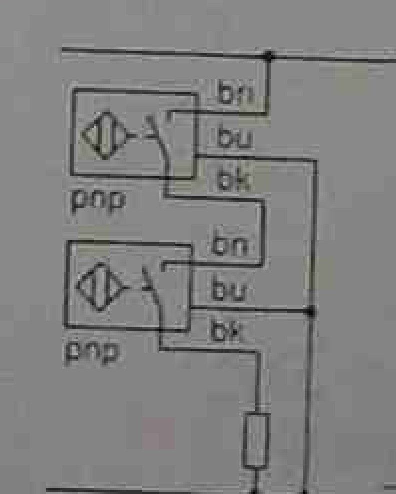


- coding: ...**-AP7** (pnp)
- coding: ...**-AN7** (npn)

- supply voltage: 10...30 VDC
- normally open (NO)
- non-short-circuit protected output
- conditional reverse polarity protected
- voltage drop ≤ 0,7 V

Series connection
of 3- and 4-wire DC-sensors

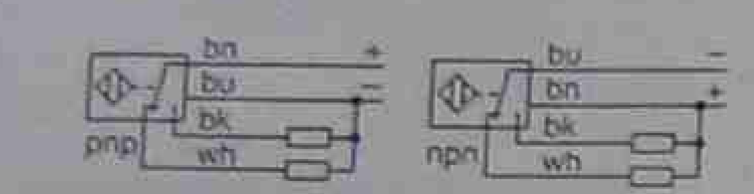
When sensors are series connected voltage drops and time delays of the individual sensors must be added.



Industrial Sensors.

Topic - ____________________

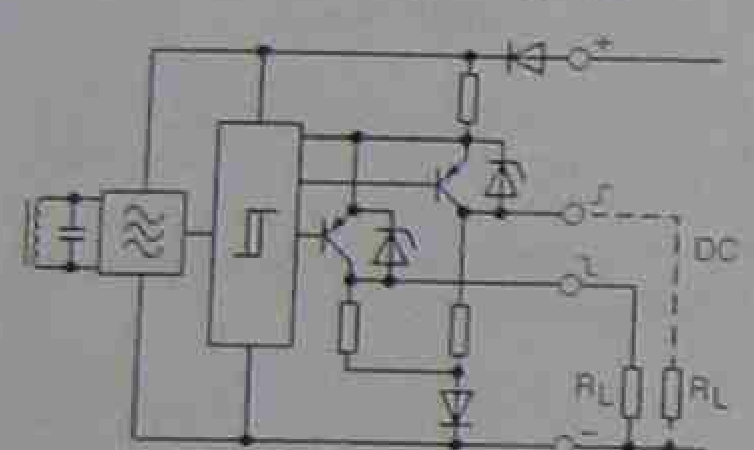
4-wire DC (Direct current)



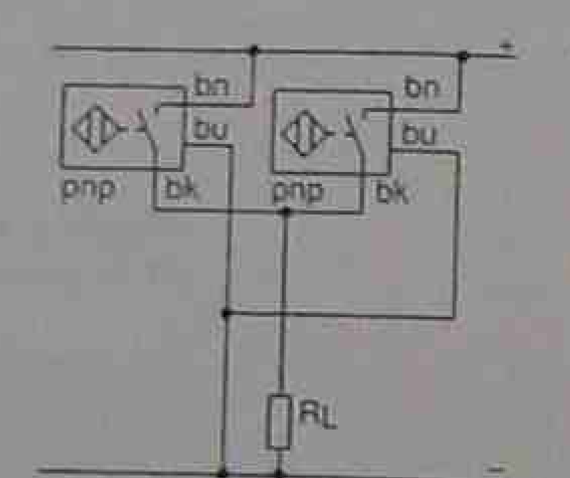
- *coding: ...-VP4 (pnp)*
- *coding: ...-VN4 (npn)*

- *supply voltage: 10...65 VDC*
- *complementary output*
- *short-circuit protected outputs*
- *complete reverse polarity protected*
- *voltage drop ≤ 1,8 V*

Principal circuit diagram (pnp)



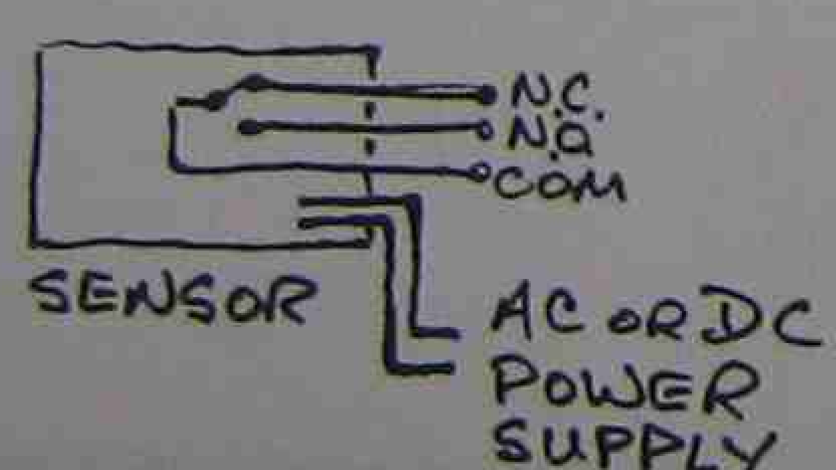
Parallel connection of 3- and 4-wire DC-sensors



5-WIRE

DC OR AC SUPPLY

N.O. & N.C. RELAY CONTACTS

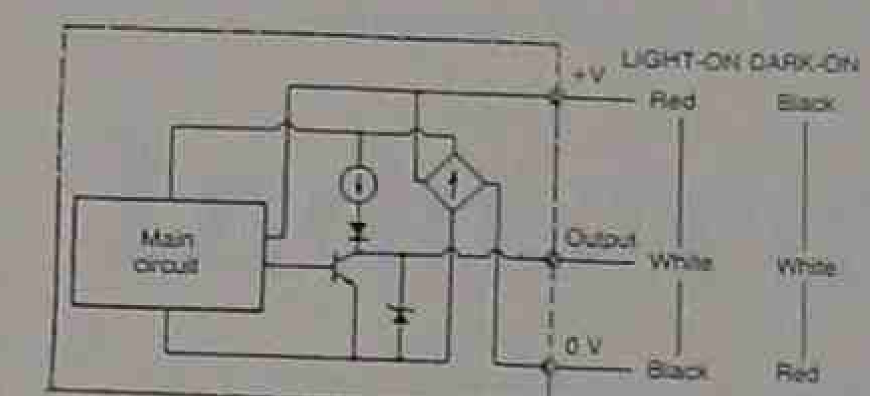


Industrial Sensors.

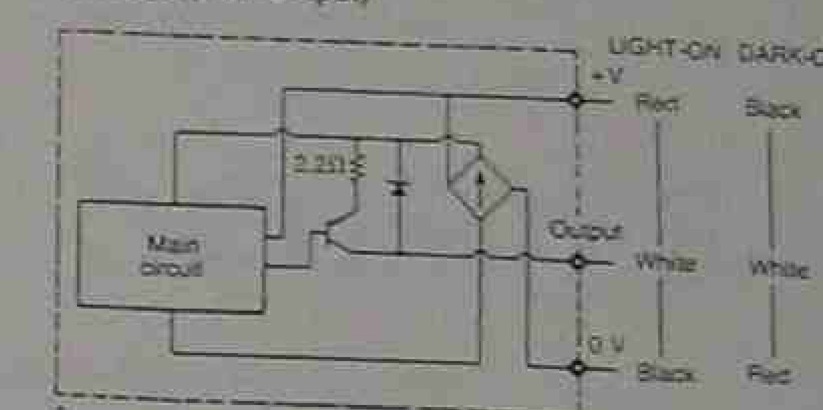
Topic - ____________________

Light source	Infrared LED
Ambient temperature	Operating: −25° to 55°C

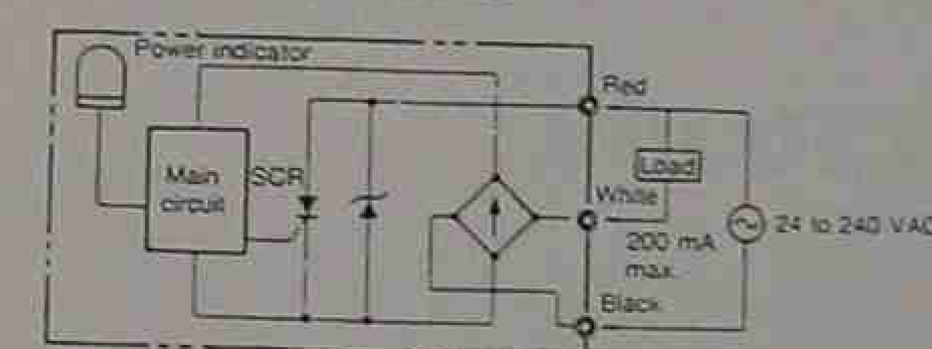
Output Stage Circuit Diagram
E3F-3□4, E3F-R2□4, E3F-DS10□4
-E4 type (NPN output)



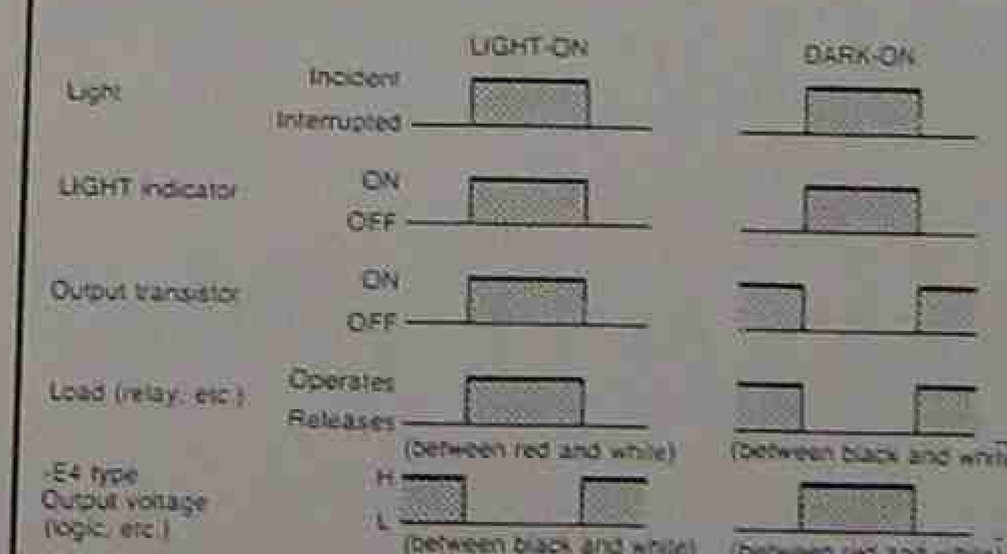
-B4 type (PNP output)



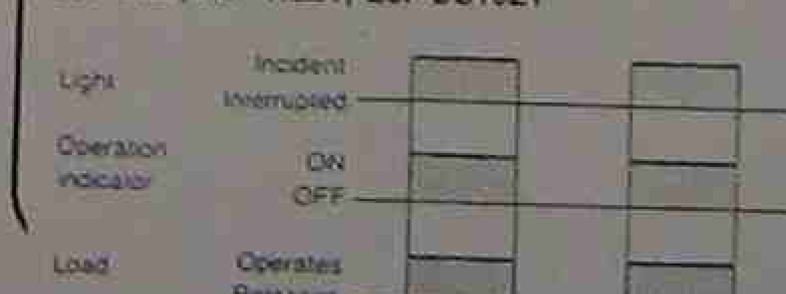
E3F-3Z□, E3F-R2Z□, E3F-DS10Z□



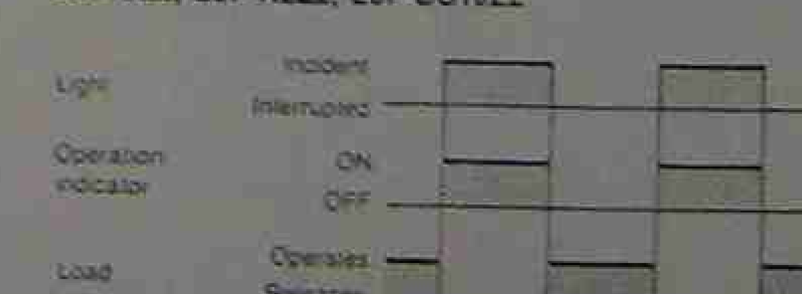
Timing Chart
E3F-3□4, E3F-R2□4, E3F-DS10□4



E3F-3Z1, E3F-R2Z1, E3F-DS10Z1



E3F-3Z2, E3F-R2Z2, E3F-DS10Z2



Sydney Institute of Technology

School of Electrotechnology

Industrial Sensors

Theory Notes

Area ______________________

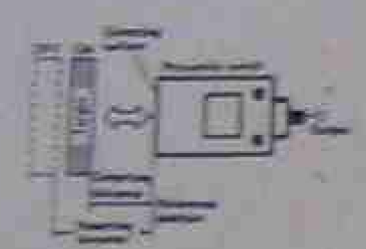
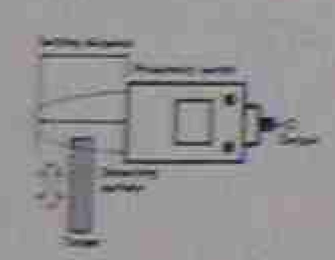
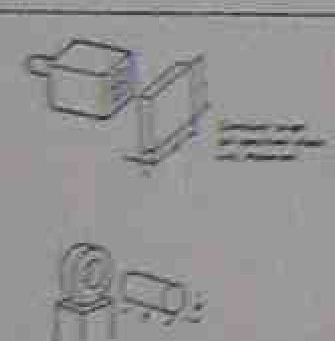
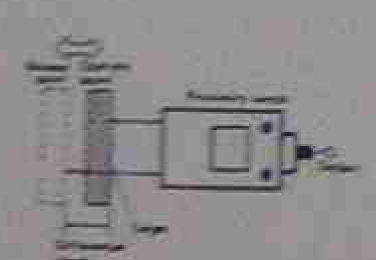
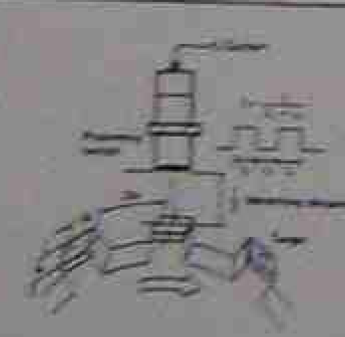
Topic ______________________

Session No. [ ]

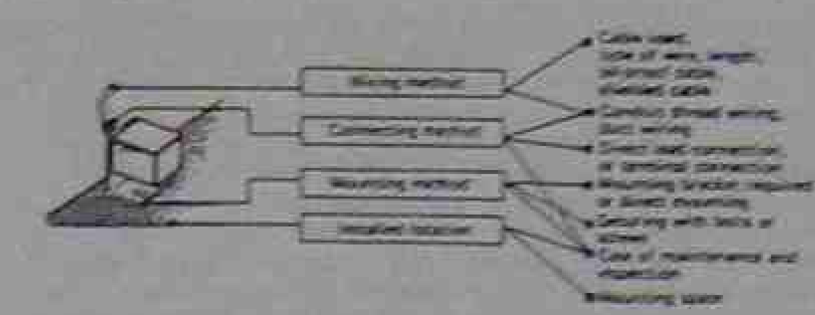
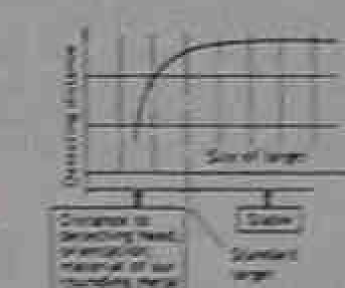
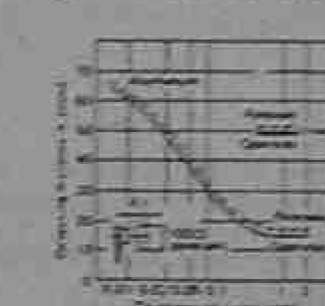
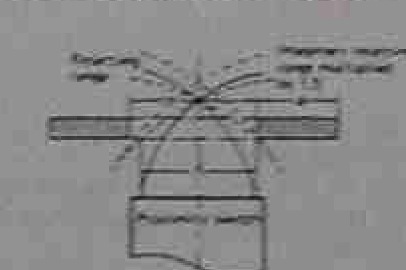
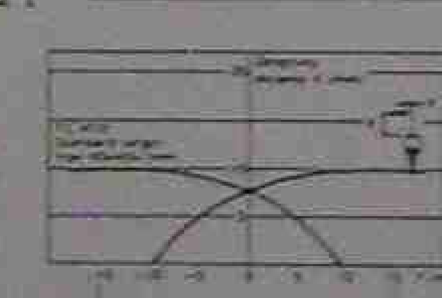
For further information on this module, or this subject contact Jim Hafford, (02) 217 3620, Bld. K. Ultimo, S.I.T.

PROXIMITY DETECTORS

Specifications

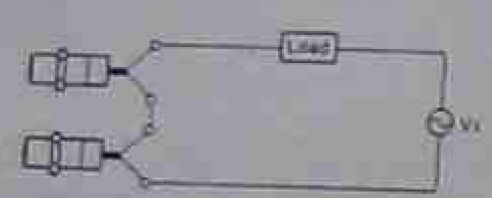
Term	Illustration	Definition
Sensing distance		• "Sensing distance" refers to the distance at which the proximity switch operates (or releases) as measured from the reference position (or reference plane) by moving the target in the specified manner. • The item "Sensing distance" under "Specifications" indicates the value(s) when measured with the standard target.
Setting distance		• "Setting distance" refers to the distance from the sensing surface to the passing position of the target which permits the proximity switch to operate without any malfunctions due to temperature or voltage fluctuation. • The item "Setting distance" under "Specifications" indicates the value(s) when measured with the standard target.
Standard target		• "Standard target" refers to a target of specified shape, size, and material which is used as a standard to examine the fundamental performance of the proximity switch.
Differential travel		• "Differential travel" is the distance between the operating point when the target approaches the proximity switch and the release point when the target moves away. • The item "Differential travel" under "Specifications" indicates the value(s) when measured with the standard target and is expressed as a percentage of the sensing distance.
Response frequency		• "Response frequency" refers to the frequency of outputs from the proximity switch per second in response to the movement of each target when brought closer to the switch. • The method of measurement is outlined on the left.
Leakage current		• "Leakage current" refers to the measured current when the output stage switching element of the AC switching type proximity switch in the OFF state.

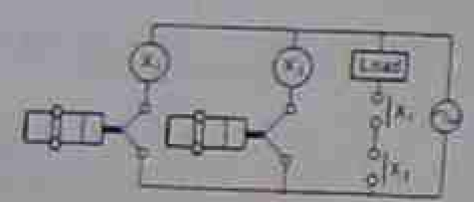
Precautions

• **Mounting condition** 	• Determine the method of mounting with consideration given to any restrictions from the machine or equipment to which the switch is attached, ease of maintenance and inspection, mutual interference, etc.
• **Size of target vs. sensing distance** 	• Referring to the size of the standard target shown in the graph "Size of target vs. sensing distance", be sure to design a target of sufficiently large size. • When the target is smaller than the standard target, be sure to provide sufficient allowance in the setting distance.
• **Nonferrous metals**	• For nonferrous metals with a thickness of more than 0.01 mm, the sensing distance is reduced compared with that for the standard target.
• **Plating**	• The sensing distance of the proximity switch changes for a plated object.
• **Thickness of target vs. operating distance** 	• For nonferrous metals with a thickness of more than 0.01 mm, the sensing distance is reduced compared with that for the standard target. • Refer to the characteristic curves of the respective types.
• **Design of a tooth disc for pulse generation**  • Response frequency $f = \frac{Y - \ell}{(Y + A)(t + \tau)}$ ——— (1) • Maximum response frequency $f_{max} = \frac{Y - \ell}{(Y + A)\tau}$ ——— (2) • Width of target Y $Y = \frac{A \cdot f_{max}\,\tau + \ell}{- f_{max}\,\tau}$ ——— (3) 	• When designing such a target as a toothed disc for pulse generation, refer to the fomulae shown on the left, where: ℓ: Length (mm) of imaginary OFF range which extended the OFF range in the operating range diagram 1.5 times in the direction of Y axis. A: Length (mm) of the target in the moving direction Y: Interval (mm) between two targets t: ON (or OFF) time duration (seconds) of output pulse τ: Response time of proximity switch f: Response frequency (Hz) For example, with the Model TL-N10 Proximity Switch, the interval between two targets which responds to a maximum of 500 Hz without fail must be designed as follows. Assuming that the size A of the standard target is 40 mm and the passing position X of the target is within a range of 0 to 6 mm, and that the OFF position in the operating range diagram shown on the left is multiplied by 1.5, ℓ under the worst condition X = 0 becomes as follows: $\ell = 26 \times 1.5 = 39$ mm Then, substitute formula (3) with the following values. $\tau = 10^{-3}$ seconds A = 40 mm $Y = \frac{40 \times 500 \times 10^{-3} + 39}{1 - 500 \times 10^{-3}}$ $= 118$ mm In other words, the proximity switch can respond to a maximum of 500 Hz when the targets, each sized 40 mm, are spaced at a minimum intervals of 118 mm.

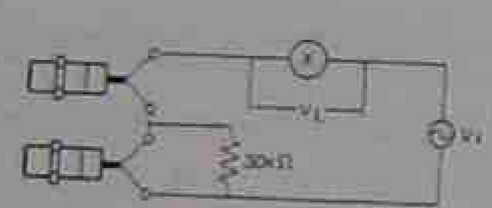
Connection to Power Source
Be sure to connect the proximity switch to the power source through a load. Direct connection of the switch may cause damage to the internal elements of the switch.

Series connection and parallel connection
(1) Series connection
Models TL-N☐MY☐, TL-F20MY☐, TL-LY50, TL-YSB☐, TL-M2MY☐, E2M-NY☐, E2K-C25MY☐
These models of proximity switches cannot normally be connected in series. If such an arrangement is necessary, it is recommended to connect switches in series or parallel through a relay.

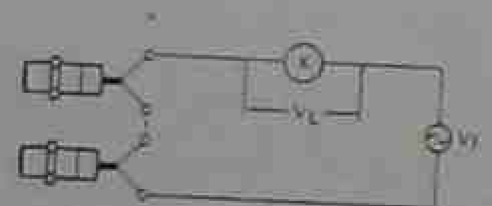




Model TL-XY(B)☐
When using two series-connected proximity switches in an AND circuit, pay attention to the following points:
(a) When the supply voltage is 100 VAC, be sure to connect a bleeder resistor of 30 kΩ (1 W min.) in parallel with either of the proximity switches.
AND operation cannot be performed without this bleeder resistor.



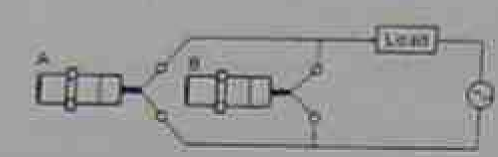
(b) When the supply voltage is 200 VAC, no bleeder resistor is required.



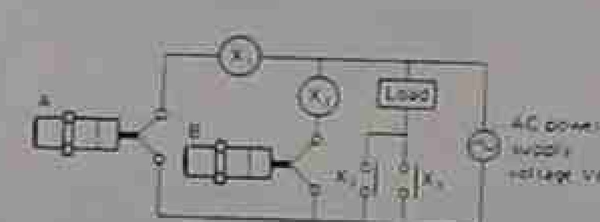
(c) At either 100 VAC or 200 VAC supply voltage, the voltage V_L applied to the load with the proximity switch in the ON state must be $V_L = V_S - 20$ (V).
If voltage V_L is lower than the operating voltage of the load, the load will not operate. It is therefore necessary to confirm the load voltage beforehand.
Be sure not to connect more than three proximity switches in series.

Model TL-X☐Y☐
When using series-connected proximity switches in an AND circuit, no more than three switches can be used. (Pay attention to the value of V_S in the following diagram.)

(2) Parallel connection
In general, two or more parallel-connected proximity switches cannot be used in an OR circuit.



Proximity switches A and B in the above example can be used in a parallel connection only when they are not required to operate simultaneously and the load is not required to be held. In this case, however, note that the leakage current increases in proportion to the number of proximity switches connected.
Proximity switches A and B cannot be used in a parallel connection when they are required to operate simultaneously to hold the load. Namely, when holding the load by operating switches A and B simultaneously, upon turning on switch A, the voltage at both ends of the switch A (B) drops to about 10 V and the load current flows through the switch A. When the target accesses to switch B, since the voltage at both ends of the switch B is 10 V, the switching element of switch B may fail to operate due to insufficient voltage. Upon turning off switch A, since the voltage at both ends of the switch A (B) rises to the supply voltage, switch B turns on at this moment. At this time, there is a moment when both switches A and B turn off (approximately 10 ms) and the load is reset momentarily. For this reason, the proximity switches are required to be used through relays to hold the load connected.



Effect of Cable Length
The operating characteristics of the proximity switches do not vary when a longer cable is used. However, use a cable no longer than 200 m taking into account the voltage drop.

Loads with high current
Loads with high current such as lamps, motors, etc., cause deterioration of, or damage to, the switching element of a proximity switch. When making or breaking such a load which exceeds the capacity of the switches listed below, be sure to use the proximity switch through a relay.
TL-X☐Y☐-50, E2P-N15Y☐: 4.2 A
TL-YS10, E2M-NY: 2.5 A
TL-X☐Y, TL-MY: 2 A
TL-XY, E2K, TL-NY, TL-FY: 1 A
TL-LY50: 1 A

Surge protection
The proximity switch is provided with a surge suppresser circuit. However, if any large surge generating source (e.g., motor, welding machine) exists in the vicinity of the proximity switch, it is recommended to insert such a surge suppresser as a varistor, into the surge generating source.

Use of a metallic conduit
If a high voltage or power line runs near the proximity switch cable, be sure to wire the switch cable through a metallic conduit to prevent the switch from malfunctioning or damage.

NOMENCLATURE

TL -☐ ☐ ☐ ☐ ☐
E2 ☐ -☐ ☐ ☐ ☐ ☐
① ② ③ ④ ⑤ ⑥ ⑦

No.	Classification	Symbol	Meaning
1	Standard model	E2	Proximity switch
2	Series	Combination of alphabet	
3	Shape of sensing head	C	Cylindrical (untapped)
		F	Horseshoe (flat for E2K-F only)
		G	Grooved head
		H	Through-hole
		L	Cylindrical, stationary
		M	Microswitch-shaped
		N	Square pillar
		Q	Square pillar (small)
		T	Slim
		W	Flat
		X	Cylindrical (tapped)
4	Sensing distance	1	1 mm
		5	5 mm
		10	10 mm
5	Shield	No indication	Shielded
		M	Non-shielded
E	Power source and output configuration	B	DC, three-wire, PNP, open-collector
		C	DC, three-wire, NPN, open-collector
		D	DC, two-wire
		E	DC, three-wire, NPN, built-in collector load
		F	DC, three-wire, PNP, built-in collector load
		H	DC, three-wire, PNP and NPN
		K	AC, relay output
		Y	AC, two-wire
7	Operation mode	1	Normally open (NO)
		2	Normally close (NC)
		4	NO/NC selectable