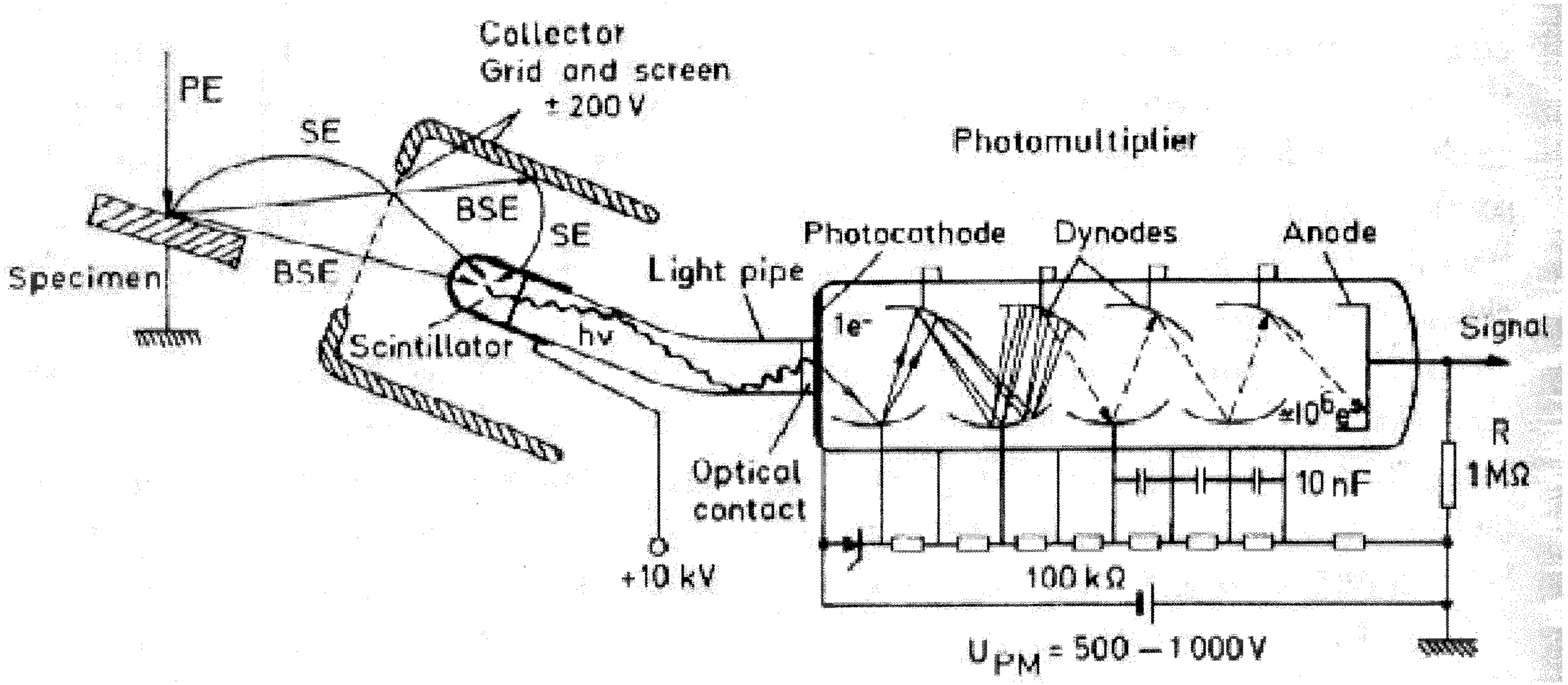
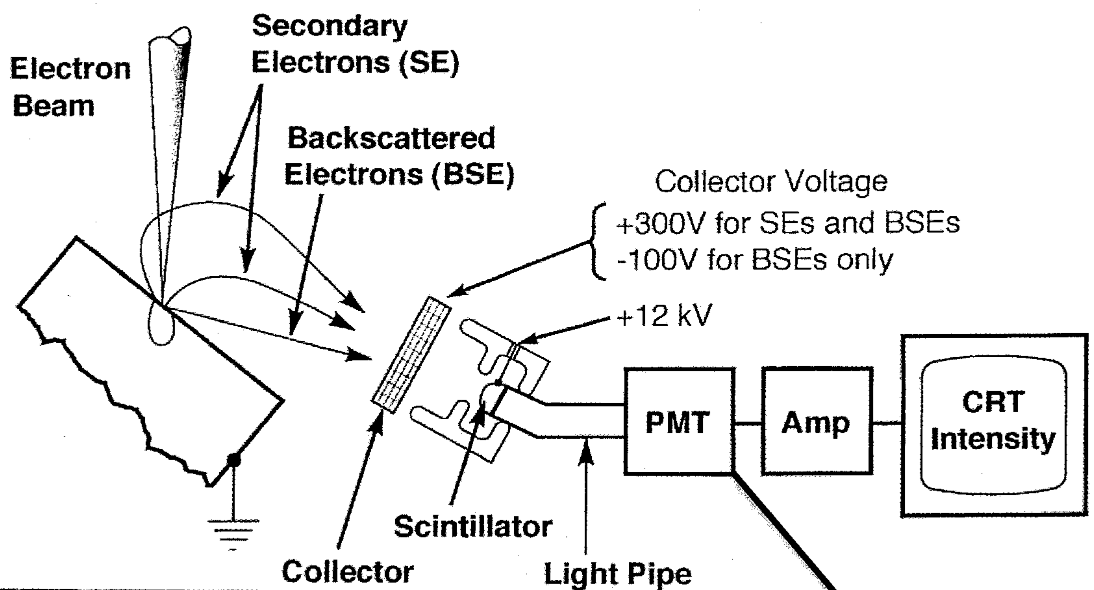
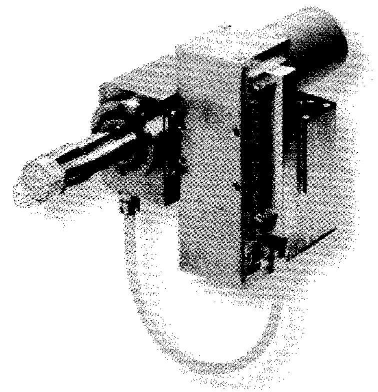
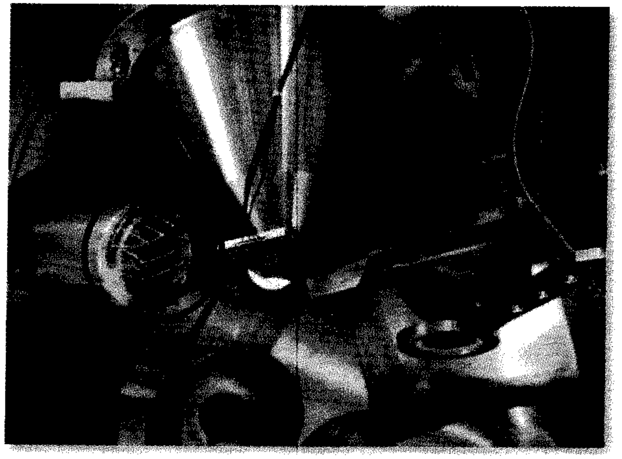
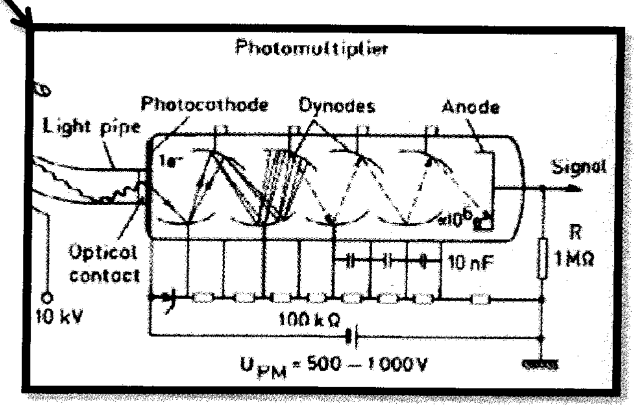

Collector
Grid and screen
+ 200 V
PE
SE
BSE
SE
BSE
Specimen
Scintillator
hv
Light pipe
Optical
contact
+10 kV
Photomultiplier
Photocathode
Dynodes
Anode
1e⁻
≈10⁶e⁻
Signal
R
1MΩ
10 nF
100 kΩ
U_PM = 500 — 1000 V

Everhart-Thornley Detector









Composition of Signals

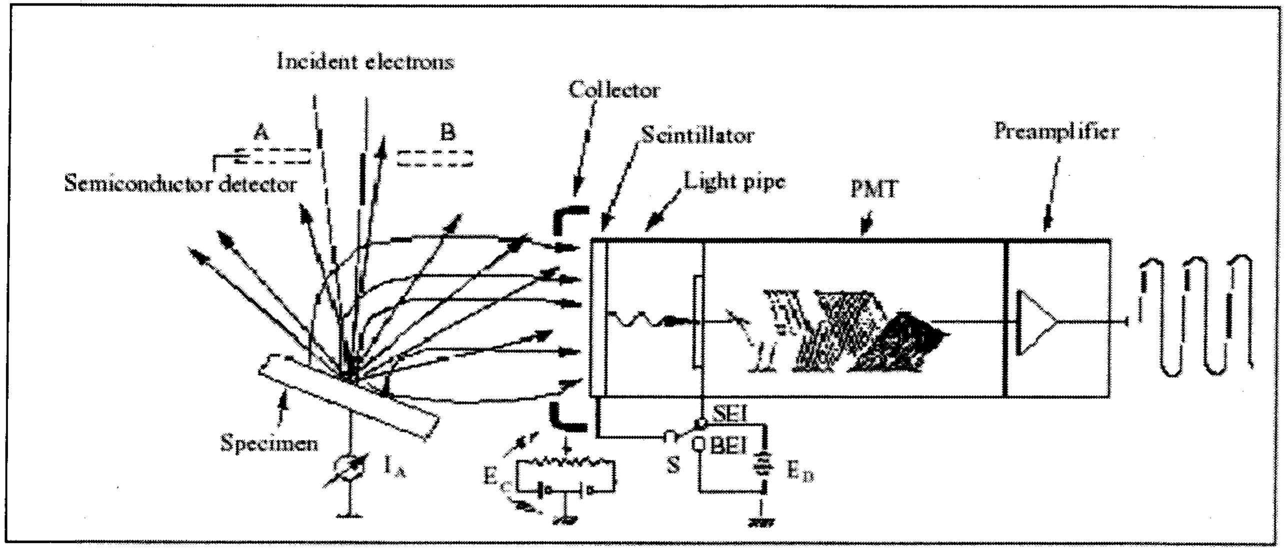


Fig. 17 Secondary electron detector

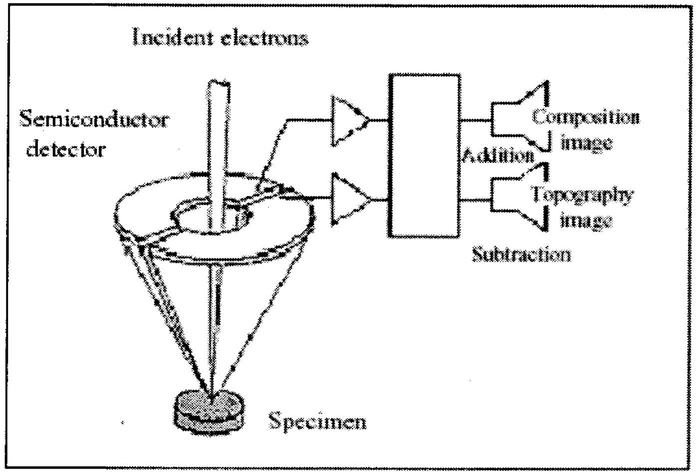


Fig. 18. Backscattered electron detector.

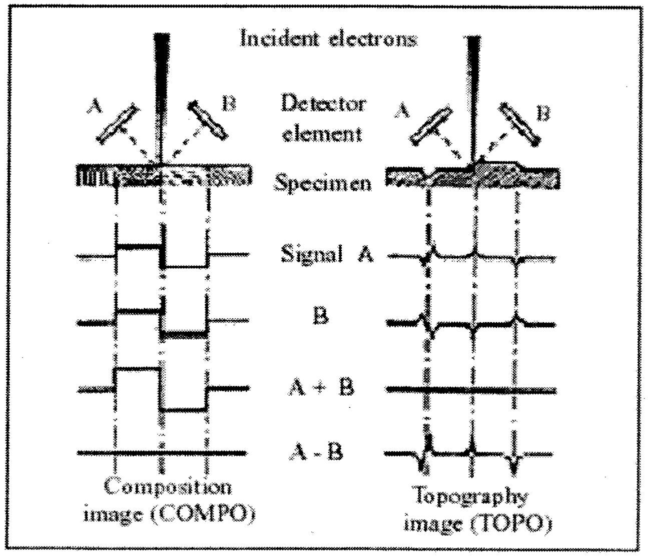
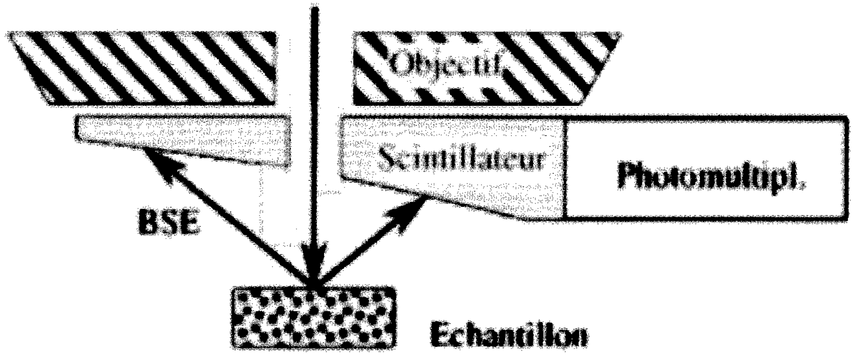


Fig. 19. Principles of composition image and topography image

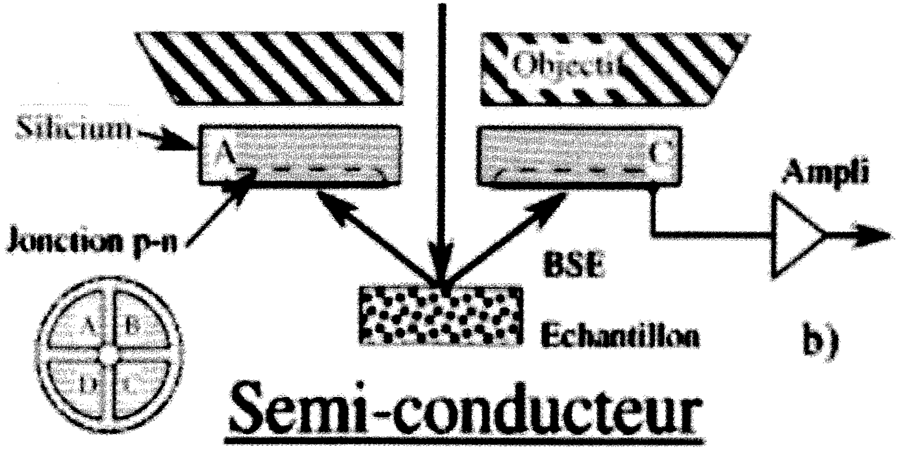
BSE detectors



Robinson

BSE Robinson detector: a large scintillator collects the BSE and guides more or less efficiently the light to a photomultiplicator

- large collection angle
- works at TV frequency

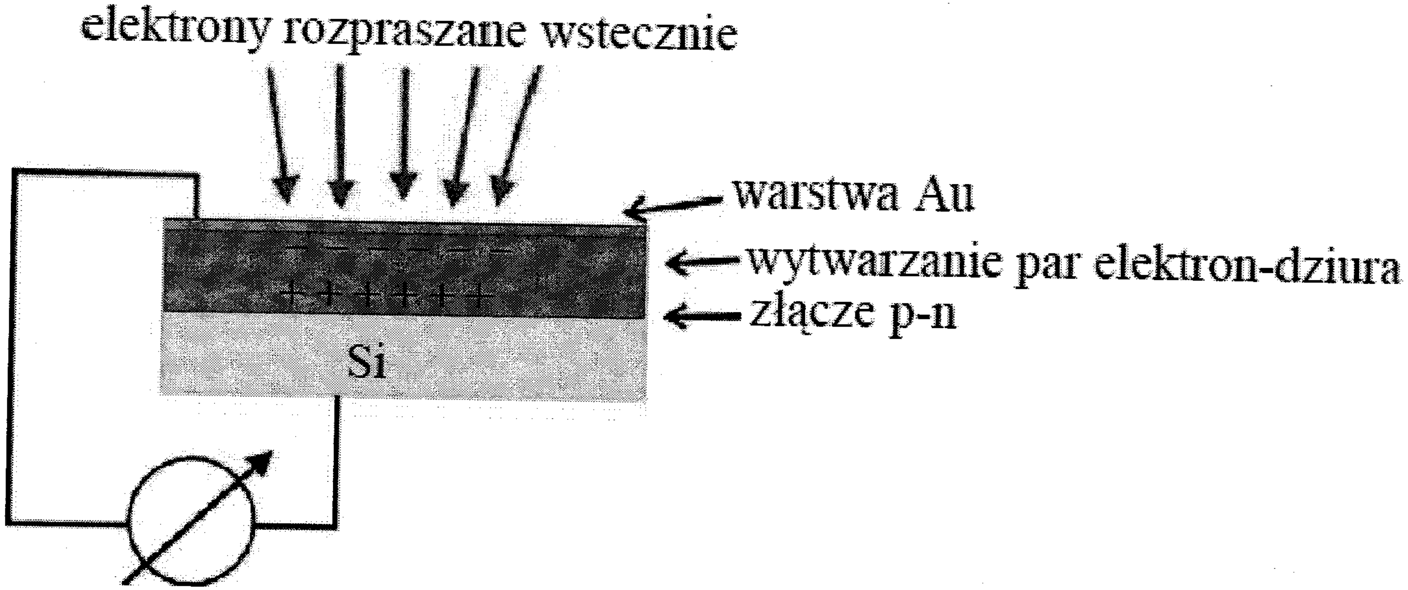


Semi-conducteur

BSE semiconductor detector: a silicon diode with a p-n junction close to its surface collects the BSE (3.8eV/e^--hole pair)

- large collection angle
- slow (poor at TV frequency)

Detekcja elektronów rozpraszanych wstecznie



Ponieważ elektrony rozpraszane wstecznie mają dużo wyższe energie, nie mogą być zbierane tą samą metodą, co elektrony wtórne. Najczęściej używanym detektorem BSE jest umieszczony nad próbką poniżej soczewki obiektywowej detektor bariery powierzchniowej. Detektor bariery powierzchniowej jest skonstruowany na bazie półprzewodnika z zapełnionym pasmem walencyjnym i pustym pasmem przewodnictwa. Na skutek bombardowania przez BSE, elektrony w z pasma walencyjnego półprzewodnika są wzbudzane do pasma przewodnictwa. Po przyłożeniu napięcia możemy rejestrować prąd proporcjonalny do liczby elektronów wtórnych.

J. H. Moore, C. C. Davis, M. A. Coplan, S. C. Greer

Building Scientific Apparatus (3)

Westview, 2002

pressure, and in this function the mechanical pump is referred to as a *backing pump* or *forepump*. In addition, it is necessary for the pressure in a vacuum chamber to be below some pressure before the high-vacuum pump can be put into operation—this pressure is sometimes referred to as the *stall pressure*. A mechanical pump is used to attain this maximum starting pressure in the chamber and in this function the pump is referred to as a *roughing pump*.

3.4.1 Mechanical Pumps

Oil-sealed rotary vane pumps. The pump most commonly used for attaining pressures down to a few millitorr is the oil-sealed rotary vane pump shown schematically in Figure 3.8. In this pump a rotor turns off-center within a cylindrical stator. The interior of the pump is divided into two volumes by spring-loaded vanes attached to the rotor. Gas from the pump inlet enters one of these volumes and is compressed and forced through a one-way valve to the exhaust. The seal between the vanes and the stator is maintained by a thin film of oil. The oil used in these pumps is a good quality hydrocarbon oil from which the high-vapor-pressure fraction has been removed. These pumps are also made in a two-stage version in which two pumps with rotors on a common shaft operate in series. Rotary pumps to be used for pumping condensable vapors (water vapor in particular) are provided with a gas ballast. This is a valve that admits air to the compressed gas just prior to the exhaust cycle. This additional air causes the exhaust valve to open before the pressures of condensable vapors exceed their vapor pressure and thus prevents these vapors from condensing inside the pump.

Oil-sealed rotary vane pumps will operate for years without attention if the inner surfaces do not rust and the oil maintains its lubricating properties. It is wise to leave these pumps operating continuously so that the oil stays warm and dry. In use, an increase in the lowest attainable pressure (the base pressure) indicates that the oil has been contaminated with volatile materials. The dirty oil should be drained while the pump is warm. The pump should be filled with new oil, run for several minutes, drained, and refilled with a second charge of new oil. For storage, a pump should be filled with new oil and the ports sealed.

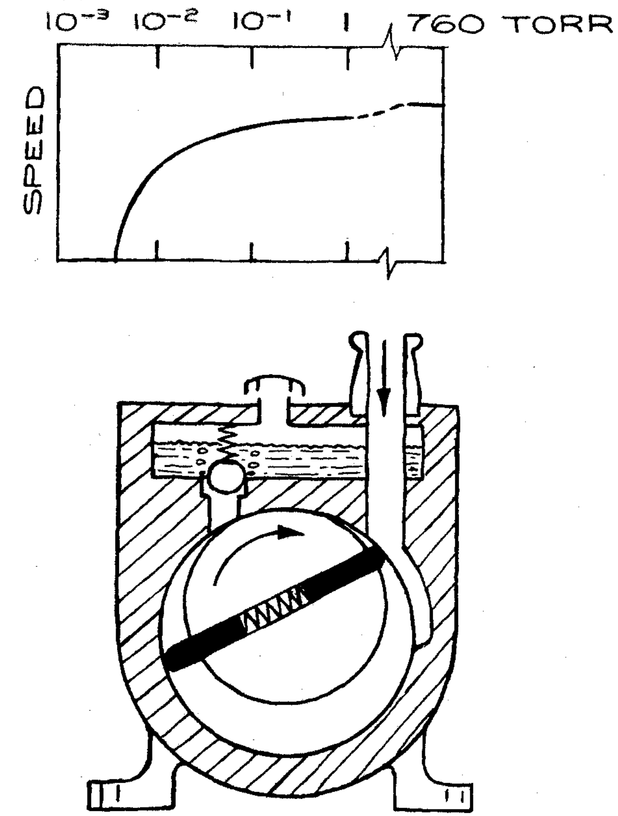


Figure 3.8 Oil-sealed rotary vane pump.

Rotary pumps are available with capacities of 1 to 500 L s^{-1}. A single-stage pump is useful down to 50 mtorr, and a two-stage pump to 5 mtorr. Typical performance of a single-stage pump is indicated by the pumping-speed curve in Figure 3.8. A two-stage pump is to be preferred as a backing pump for a diffusion pump. With a two-stage pump, a base pressure of 10^{-4} torr can be achieved after a long pumping time if the back diffusion of oil vapor from the pump is suppressed by use of a sorption or liquid-air trap on the pump inlet. This is a simple scheme for evacuating small spectrometers and Dewar flasks or other vacuum-type thermal insulators.

The exhaust gases from an oil-sealed mechanical vacuum pump contain a mist of fine droplets of oil. This oil smoke is especially dense when the inlet pressure exceeds 100 torr. The oil droplets are extremely small, usually less than 5 microns. Over the course of time, this oil settles on the pump and its surroundings and collects dirt and grime. Furthermore, breathing the finely-dispersed oil may injure the operator's lungs. In addition, over the course of weeks or months, this oil represents a significant loss from the oil charge in the pump. A pump failure may result if the oil level in the pump is not faithfully monitored. Most pump manufacturers market filters that cause the exhaust oil mist to coalesce and run back into the pump; their use is recommended. In addition, modern standards of laboratory hygiene require venting a mechanical pump into the laboratory fume hood. If toxic gases are being pumped, it is, of course, essential to pipe the exhaust out of the lab. Sometimes a pretreatment involving passage of the exhaust through a neutralizing chemical bath is required. In most cases, exhaust lines can be made of PVC drain pipe available from plumbing suppliers. The exhaust line should rise vertically from the pump so that oil in the exhaust will collect on the walls of the line and run downward back to the pump. An exception to this scheme arises in the case of a wet vacuum process. If considerable water is exhausted from the pump, there is the danger that water will condense in the exhaust line and run back into the pump.

Roots blowers. A Roots blower is a displacement pump. As illustrated in Figure 3.9, these pumps consist of a pair of counter-rotating two-lobed rotors on parallel shafts. Rotational speeds are about 3,000 rpm. There is a clearance of a few thousandths of an inch between the rotors themselves and between the rotors and the housing. A volume of gas is trapped at the inlet and compressed as it is moved to the exhaust. There is no oil in the body of the pump to maintain a high-pressure seal, but owing to the high speed of the pumping motion a compression ratio as great as 40:1 can be achieved. The virtue of the Roots blower is its relatively high pumping speed in the 1 to 10^{-3} torr region. To achieve an ultimate vacuum of 10^{-3} torr, a Roots blower is used in series with a rotary pump at its exhaust. The required speed of the rotary pump is smaller than that of the Roots pump by a factor of the inverse of the compression ratio of the Roots pump. Roots blowers are available with speeds of a few hundred to many thousand Ls^{-1}.

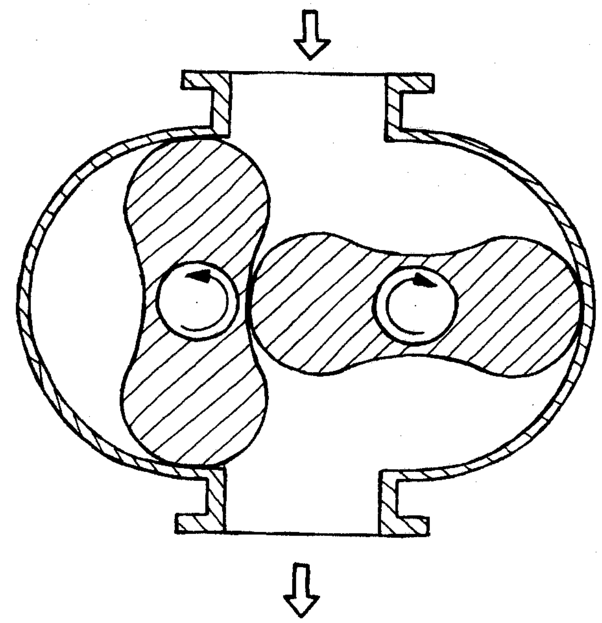


Figure 3.9 Roots blower.

Piston pumps. Now available are piston pumps with Teflon-sealed pistons that do not contaminate the vacuum environment with oil as do oil-sealed rotary pumps. The Leybold EcoDry pump employs a novel diaphragm exhaust valve that permits a higher compression ratio than pumps with poppet valves. The low-pressure limit of these pumps is about 50 mtorr. Piston pumps are robust and reliable, but they are also relatively expensive in comparison to rotary pumps. They find use as backing pumps for pumps such as turbomolecular pumps when contamination with hydrocarbons is not permissible.

Diaphragm pumps. Diaphragm pumps are displacement pumps employing the flexure of a thin metal or Teflon diaphragm to compress gas and drive it out through an exhaust valve. These are small pumps of low pumping speed and relatively modest ultimate vacuum. The low pressure limit is typically about 1 torr. Diaphragm pumps can be made completely free of hydrocarbons, so they are used as roughing pumps and in some applications as backing pumps in ultraclean systems.

Molecular drag pumps. A molecular drag pump incorporates a rotating cylinder within a closely fitting, stationary cylinder. The clearance between rotor and stator is of the order of 0.01 in. Pumping occurs when the surface velocity of the rotor approaches the velocity of the molecules being pumped so that molecules striking the rotor acquire a significant velocity component tangential to the rotor—they are dragged along with the rotor. Tangentially accelerated gas molecules rebounding to the stator are decelerated—they *pile up*, thus yielding compression. The process is repeated continuously around the gap between rotor and stator. Helical grooves on the surface of the rotor or stator direct the flow of continually compressing gas toward the pump outlet. Drag pumps provide efficient pumping at inlet pressures from nearly 1 torr down to about 10^{-6} torr. The *compression ratio* for air (that is, the ratio of outlet to inlet pressure) is typically 10^7 at the low-pressure end of this range. As a consequence, the exhaust pressure (that is, the critical backing pressure) falls in the 1 to 10 torr range. The practical result is that a very small pump is required to transfer the drag pump throughput to the atmosphere. Small diaphragm pumps serve well as backing pumps for molecular drag pumps.

The chamber pressure at the inlet must be below about 1 torr for a drag pump to begin to operate efficiently; therefore, a roughing pump is necessary. The backing pump, pumping through the drag pump, can serve to rough down the chamber. The gap between rotor and stator, however, is small and restrictive in the viscous flow regime. A separate roughing pump or a bypass (with a valve) from the chamber to the backing pump should be provided.

Molecular drag pumps provide modest pumping speeds at high vacuum—the inlet aperture is effectively the gap between rotor and stator. Drag pumps are currently available with pumping speeds of up to 30 L s^{-1}. The great virtue of the drag pump is the relatively high throughput in the 1 to 10^{-3} torr pressure range. Displacement pumps such as rotary-vane pumps, piston pumps, and Roots blowers, lose efficiency below 0.1 torr. High vacuum pumps such as diffusion pumps, turbomolecular pumps and ion/getter pumps, *stall* at pressures above 0.01 torr. If pumpdown time is an important issue, a molecular drag pump may be a good choice for a small vacuum system roughing/backing pump and a drag pump of 30 L s^{-1}, a volume of 100 L can be evacuated to less than 10^{-4} torr in a matter of minutes.

Turbomolecular pumps. Turbomolecular pumps operate in the molecular flow regime. The construction is similar to that of an aircraft-type jet turbine engine. A series of bladed turbine rotors on a common shaft turn at 20,000 to 90,000 rpm. The edge speed of a rotor approaches molecular velocities. The rotor blades are canted so that a molecule striking a blade receives a significant component of velocity in the direction of the pump exhaust (Figure 3.10). Bladed stators are interleaved between the rotors. The stator blades are canted in the opposite direction from that of the rotors in order to decelerate the molecules and compress the flowing gas before it is delivered downward to the next rotor-stator pair. These pumps provide roughly the same pumping speed for all gases; however the compression ratio depends upon the nature of the gas being pumped. A single rotor-stator pair typically provides a compression ratio of about 10 for N_2. To a first approximation, the logarithm of the compression ratio is proportional to the square root of the molecular weight of the gas. For example, a multistage pump with eight rotors may have a compression ratio of 10^8 for N_2, but only 10^2 to 10^3 for H_2. A desirable consequence of the strong dependence upon molecular weight is that the compression ratio is very high for oil vapor backstreaming from the pump bearings or from the pump exhaust. A turbo pump therefore provides an essentially oil-free vacuum. The compression ratio is extremely sensitive to the pressure at the outlet of the pump. A typical turbopump may have a compression ratio of 10^8 for air if the pressure at the exhaust is maintained below 0.1 torr, but if the exhaust pressure rises to 1.0 torr, the compression ratio falls to 10.

A turbomolecular pump is usually run in series with a conventional oil-sealed rotary pump as a backing pump. The backing pump also serves as a forepump. With the vacuum chamber at atmospheric pressure, the rotary pump is activated to evacuate the chamber, drawing gas directly through the body of the turbopump. Depending on the manufacturer's specification, the turbo is activated at the

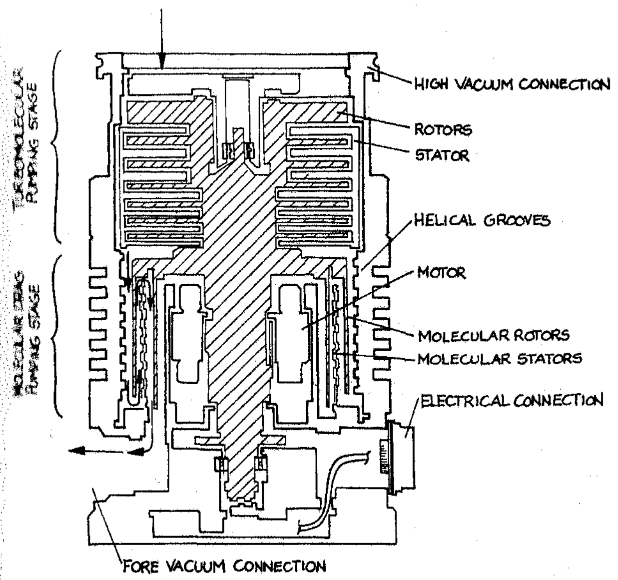


Figure 3.11 Compound turbomolecular/molecular drag pump.

should be admitted slowly so that turbulence does not carry debris into the turbopump.

Careful and systematic startup and shutdown procedures are essential to protect the turbopump and to exclude oil from the vacuum system. As mentioned above, turbos are usually operated without a valve at the inlet; however a valve is required in the *foreline* between the turbo outlet and its backing pump. At startup with the turbo and the vacuum system at atmospheric pressure, the backing pump is activated and the foreline valve is opened. The rush of dense gas into the backing pump prevents oil from backstreaming. As the pressure falls, the turbo activation is timed so that the turbo is up to at least 50 percent of its maximum speed before the pressure at the pump inlet falls below a few hundred millitorr. At this point, the turbo compression should be sufficient to prevent oil vapor from backstreaming to the vacuum system. At shutdown, the foreline valve is closed immediately after power is cut from the turbo. The vacuum system should be vented before the rotor falls below 50 percent of its maximum speed—again so that the compression ratio is sufficient to prevent backstreaming of oil from the bearings. When the pressure has risen above

impossible. It follows that a pump that is not operating should not be stored under vacuum. It also should be emphasized that the pump must be vented above the outlet. Many manufacturers sell turbopumps and controllers as a complete system that incorporates the necessary valves and timing circuits to automatically perform the startup and shutdown procedures.

A turbomolecular pump offers many advantages for high- or ultrahigh-vacuum systems. Of course these must be weighed against the disadvantages, the main one being the relatively high initial cost and the cost of major servicing. A complete turbomolecular pump system may cost two or more times as much as a comparable diffusion-pump system. Turbomolecular pumps with pumping speeds from 10 to 1000 L s^{-1} are available. A turbopumped system can achieve pressures below 10^{-10} torr. Most gases can be pumped, although as noted turbos do not efficiently pump hydrogen and helium. Most corrosive gases are acceptable providing the bearing lubricant does not come under attack. Turbopumps are compact and relatively light in weight; they need not be mounted on the underside of a vacuum system. For many types of pumps, the mounting orientation is not critical—these can be mounted with the axis horizontal. Turbos can be baked to reduce outgassing and many are equipped with heating jackets for this purpose. A turbo can be used on a system that is to be baked provided the inlet temperature does not exceed 100 to 120°C. Magnetic fields can be a problem as eddy currents induced in the aluminum rotor assembly cause heating. The specification for most pumps calls for magnetic fields not to exceed 50 to 100 gauss at the inlet. A turbomolecular pump can run for one to three years without attention. The major maintenance procedure usually involves replacing the bearings and rebalancing the rotor. These procedures often require the pump to be returned to the manufacturer.

3.4.2 Vapor Diffusion Pumps

In a diffusion pump, gas molecules are moved from inlet to outlet by momentum transfer from a directed stream of oil or mercury vapor. As shown in Figure 3.12, the working fluid is evaporated in an electrically heated boiler at the bottom of the pump. Vapor is conducted upward through a tower above the boiler to an array of nozzles