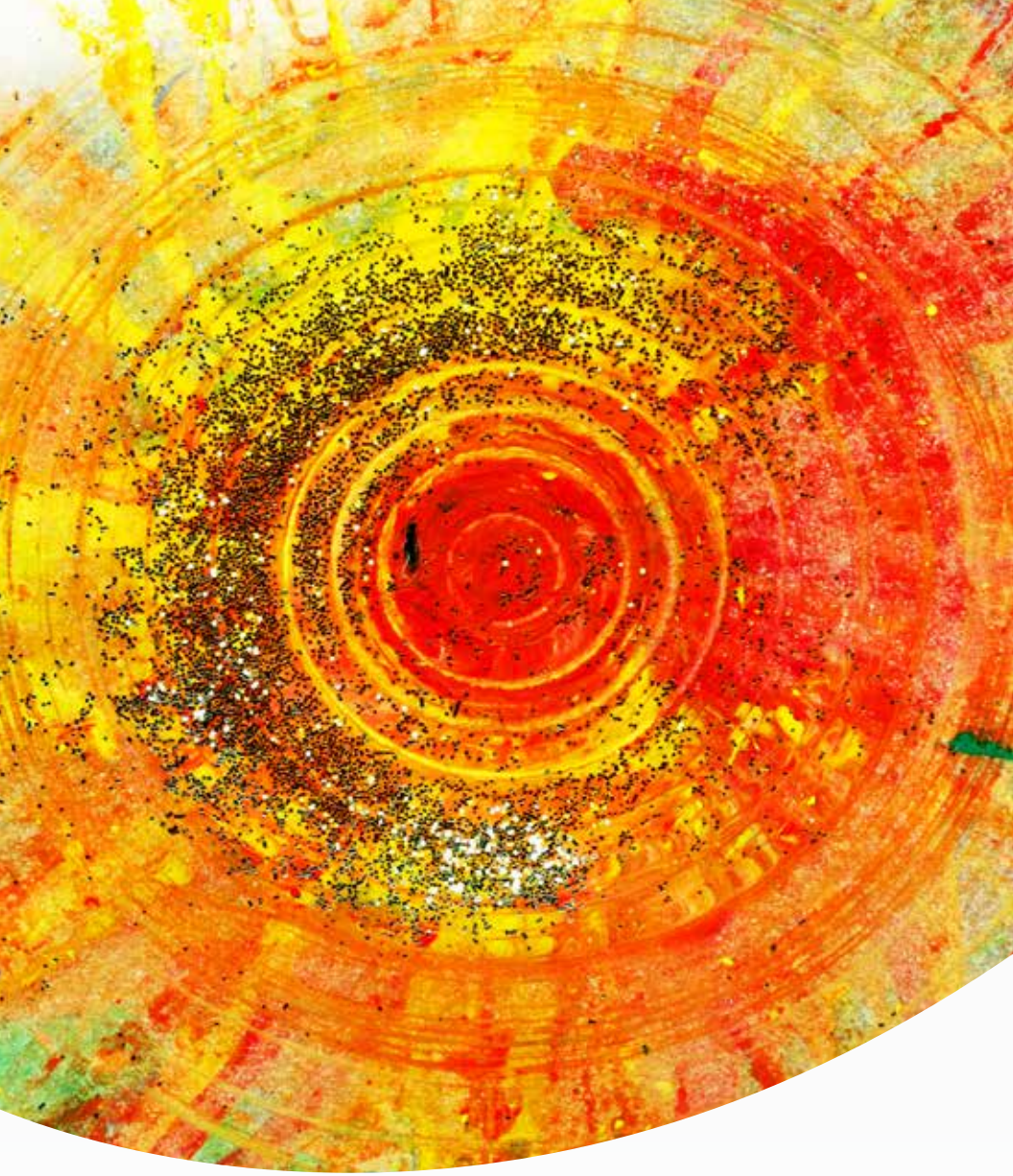

A CENTRIFUGE PRIMER

BECKMAN COULTER
Life Sciences

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FIGURES

PREFACE

You may have operated a centrifuge before. Or perhaps this is your first day on a new job at a new lab or Life Science facility. Whatever the case may be, you may have some questions about centrifuges and their operating principles.

This booklet is meant to supplement your instruction manual. It provides an overview on basic centrifugation operating principles. We think you'll be a better centrifuge operator if you understand why separations can be made using centrifugal force. Directions for how to operate a centrifuge are in your manual.


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COULTER

THE CENTRIFUGE

Centrifuges have three basic components:

- A rotor
- A drive shaft
- A motor

The rotor holds the tubes, bottles, or bags containing the liquids to be centrifuged. It is usually constructed of a high strength material such as an aluminum alloy or stainless steel. Different rotor types and sizes, interchangeable with one another, can be mounted on the drive shaft, which connects to the motor. The motor provides the power to turn the rotor.

Usually, a cabinet surrounds and supports these parts, and also protects the operator should a tube break or any metal parts fail while the centrifuge is running. The operating controls and indicator dials for speed and time are mounted on the cabinet. Most centrifuges have a brake system to bring the rotor to a standstill shortly after the run is finished. Unlike the mechanical brakes on a car, the braking action is electrical: the current to the motor is simply reversed. Many centrifuges are also refrigerated to prevent delicate biological samples from getting warm.

As illustrated at the left, there are two centrifuge configurations: floor model and tabletop. The difference between the two is basically one of capacity; their operating principles are the same.

OPERATING PRINCIPLES

During operation, the centrifuge rotor turns rapidly, up to 6000 revolutions per minute in the case of many laboratory centrifuges. This rotation generates a *centrifugal field*, which can be used to make separations.

To visualize this centrifugal force field, imagine you have a stone tied to a string which you're whirling in a circle. The force you experience pulling against your hand is called *centrifugal force*. It arises whenever a body is made to move along a curved path, and is thus continuously deflected away from the direction it "prefers" to go---which is in a straight line. The term centrifuge, in fact, means *to flee from the center.*

If you whirl the stone faster, the pull becomes stronger. If you slow down or shorten the string, the pull decreases. Clearly, the strength of a centrifugal force field increases with the speed of rotation. It also increases with the distance from the center of rotation; the centrifugal force at a point 6 inches from the center is twice what is at only 3 inches.

How can we describe and compare the strength of the fields generated by different size rotors and different operating speeds? The expression *relative centrifugal field* (**RCF**) serves this purpose. Just as length is measured in units of inches or millimeters, time in units of hours or minutes, the relative centrifugal field is measured in units also. It is expressed in multiples of the earth's gravitational field, abbreviated *g*.

CALCULATING CENTRIFUGAL FIELDS

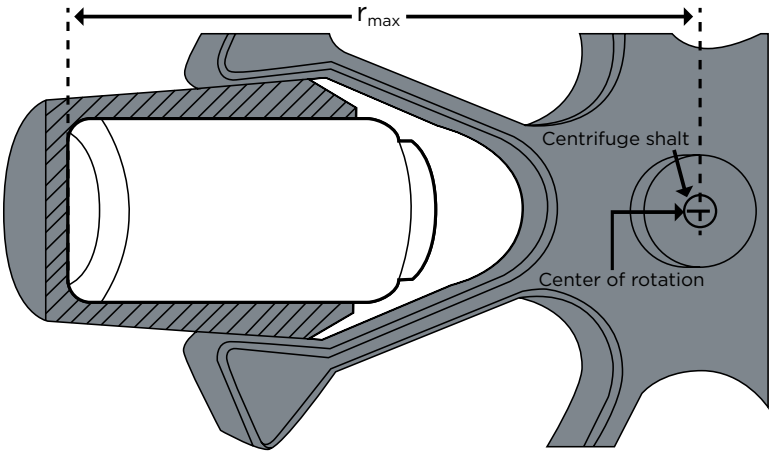
There's a simple formula for calculating the strength of a particular centrifugal field:

Equation 1

$$RCF = 1.12r\left(\frac{RPM}{1000}\right)^2$$

where ***r*** stands for the radius, which is the distance in millimeters (mm) from the center or rotation to some point within the rotor, and **RPM** is the speed of rotation in revolutions per minute (rpm). Sometimes radial distances are given in centimeters. Before using them in this equation, you must first convert them to millimeters (multiply by 10).

To find the maximum RCF of a rotor, you need to know its maximum speed and it maximum radius (r_{max}), the distance from the center of rotation to the bottom of the rotor cavity or bucket during centrifugation (see illustration below). Almost all centrifuge manufacturers publish this information for their rotors in their instruction manuals.



For example, the maximum RCF of the JS-4.2 rotor can be obtained from its maximum speed (4200 rpm) and its r_{max} (254mm) as follows:

$$RCF = 1.12r\left(\frac{RPM}{1000}\right)^2 = 1.12 \times 254 \times \left(\frac{4200}{1000}\right)^2 = 5018 \times g.$$

If this same rotor is run at a lower speed, say 2000 rpm, the RCF it generates will also be lower:

$$RCF = 1.12 \times 254 \times \left(\frac{2000}{1000}\right)^2 = 1138 \times g.$$

Since the RCF varies with the square of the rotor speed, you can see that any change in speed will cause a much greater change in RCF.

SEPARATION BY SEDIMENTATION

How can a centrifugal field be used to separate particles from a mixture—blood, for instance?

Blood consists of plasma (which is a solution of water and many other compounds) and several kinds of particles in suspension, namely: red cells, white cells, and platelets. These cells are fairly large for biological particles—large enough, in fact, to settle out of the plasma if clotting is prevented and the blood is left standing in the 1-*g* field of the earth's gravity overnight. By using a centrifuge to generate an RCF of 1500 × *g*, we can speed up this sedimentation process and separate the cells from the plasma in approximately 10 minutes.

Why does this happen so quickly in a centrifugal field? Because the force which moves each cell away from the center of rotation is many times greater than the cell's own weight in the earth's normal gravitational field—1500 times greater, in the example above.

Not all cells sediment at the same rate: large ones sediment faster than small ones. Thus, one kind of cell can be separated from another if there is a sufficient difference in size and sedimentation rate.

Platelets, for instance, can be separated from red and white blood cells because they are so much smaller. It's only necessary to pick the right combination of centrifugal force and time. If blood is spun at 2900 × *g* for just 3 minutes, the platelets will not have time to move down with the heavier cells and can be collected from the top platelet rich plasma.

The process just described produces a *pellet* or sediment of particles in the bottom of the tube or other container. The liquid above the pellet is called the *supernatant*. As you can see from Figure 1, it is possible to collect a fairly pure fraction of the smallest particles from the supernatant. But the pellet or larger ones will always contain some of the smaller ones, which were near the bottom of the tube before centrifugation began. By centrifuging at various speeds and times, different size particles can be separated and collected from a mixture. This method is called *differential centrifugation*.

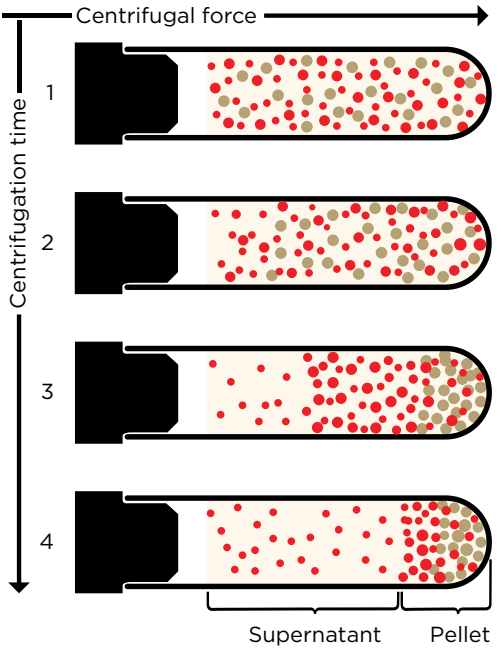


Figure 1. Sedimentation in a Centrifugal field

DENSITY SEPARATIONS

There's another physical property of particles or cells, which can also be exploited for the purpose of making separations: *density.*

Consider an apple, and a rock of exactly the same size and shape. A rock is a much more compact material than an apple, hence it sinks in water while an apple floats. It has more mass per unit volume, which is another way of saying its density is greater. Density is commonly expressed as grams per milliliter (*g*/mL); water has a density of 1 *g*/mL.

By applying centrifugal force, we can separate particles with small difference in density. It's only necessary to adjust the density of the liquid in which they will be sedimenting so that particles of one density will float, and particles which are more dense will sink.

This method is often used to separate lymphocytes, a type of white blood cell, which are so similar in size to many other blood cells that they can't be separated by ordinary sedimentation methods. However, their density is lower than the other cells. If a blood sample is layered over a liquid which has a density of 1.077 *g*/mL and then centrifuged, the lymphocytes will form a floating band, well separated from most other white and red cells which, being denser than 1.077 *g*/mL, sediment to the bottom of the tube. Plasma and platelets, the least dense of all, float to the top as illustrated in Figure 2.

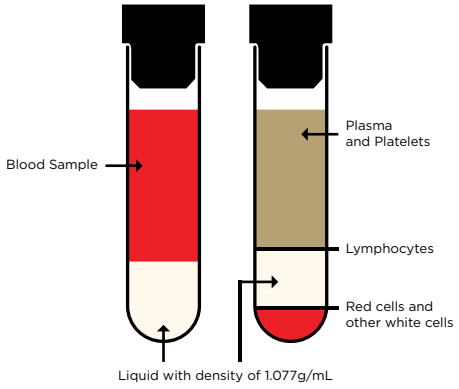
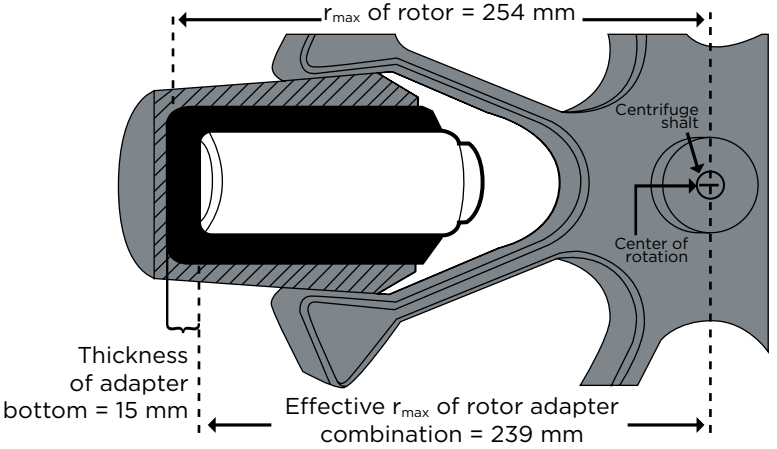


Figure 2. Density Separation of Lymphocytes. Tubes are shown before and after centrifugation

DUPLICATING CENTRIFUGE RUN CONDITIONS

In your research it is often necessary to replicate run conditions you see in published protocols. When reviewing these protocols make sure the instructions offer complete run information, including the rotor's name or max radius, RPM or RCF, and run time. For example, unless a rotor is also specified, or its maximum radius given, there's no way to know what RCF is required to achieve that separation. A rotor such as the JS-5.2 with an r_{max} of 226mm generates 4050 x *g*. This difference of 500 x *g* seems small, but it is large enough to affect the results of certain separations if disregarded. The preparation of blood components or the pelleting step specified by radioimmunoassay (RIA) kits are examples of separations which require careful attention to the conditions of centrifugation.

Many adapters designed to carry a number of small tubes have bottoms, which are 10-15 mm or more thick. Most separations won't be affected by this small reduction in the effective r_{max}. But if you need a more accurate calculation of RCF when using such adapters, you'll have to subtract the thickness of the adapter bottom from the r_{max} of the rotor to obtain the effective r_{max} for that rotor adapter combination (see illustration below).



This is not to say that a run made in one rotor cannot be duplicated in a rotor with a different r_{max}. The same results can be achieved, but a change in rotor speed (or run time) must be made to compensate for the difference in r_{max}. See the nomogram for speed selection on page 18. By following instructions given there, you can estimate RCF's and speeds for rotors of various radii.

You can also calculate the proper speed to use by means of the equation already given on page 3. Let's say you want to follow a procedure written for a rotor with an r_{max} of 250 mm which calls for an RCF of 3430 x *g*. You want to duplicate these conditions in the Beckman Coulter JS-5.2 which has an r_{max} of 226 mm. In this case you need to transpose the equation to solve for speed in rpm, so $RCF = 1.12r(RPM/1000)^2$ becomes

$$RPM = 1000\sqrt{\frac{RCF}{1.12r}} = 1000\sqrt{\frac{3430}{1.12 \times 226}} = 3681\ rpm$$

Thus, the JS-5.2 rotor will produce an RCF of 3400 x *g* if run at about 3681 rpm. If the original directions had specified the speed and radius of the rotor to be used, rather than the RCF, you would first have to find the RCF that combination generated, by means of the nomogram or the equation as shown on page 3.

Sometimes it may be better to change the length of time samples are centrifuged than to change the centrifugal force. You might want to duplicate a procedure calling for 10 minutes of centrifugation at 3000 *g*. Can you use a JR-3.2 rotor which attains a maximum RCF of 2300 x *g*? Yes, but you'll have to run the samples a bit longer. The time required can be found with this equation:

Equation 2

$$t_1 = \frac{t_2 \times RCF_2}{RCF_1}$$

where

$\mathbf{t_1}$ = run time needed for JR-3.2 rotor
$\mathbf{t_2}$ = run time specified in procedure
$\mathbf{RCF_1}$ = RCF of JR-3.2 rotor at maximum speed
$\mathbf{RCF_2}$ = RCF specified in procedure

Thus, in our example,

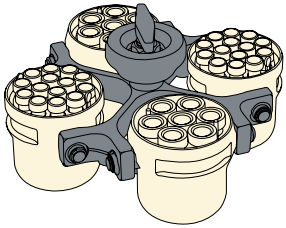
$$t_1 = \frac{10 \times 3000}{2300} = 13 \text{ minutes}$$

Directions given for times of centrifugation usually correspond to the times to be set on the centrifuge's time control. This setting includes time for the rotor to accelerate and time at operating speed, but not deceleration time. The latter depends on the weight of the rotor, including its load, the type of brake system, and the brake setting selected by the operator. If a maximum bake setting is used, a fully loaded rotor takes somewhere between 1 and 3 minutes to decelerate.

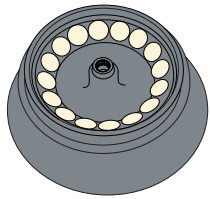
Sedimentation of particles in the sample continues during deceleration, of course, but the rate decreases as the rotor slows. Minimum deceleration times can be obtained by use of maximum brake settings. However, maximum braking in the final phase of rotor deceleration may be too abrupt when large diameter bottles or blood bags are in use; the result may be some undesirable stirring and re-suspension of the sedimented material. The presence of this resuspended material can easily be mistaken for a poor separation.

A word of caution: before you change centrifugation conditions be very sure your particular sample will not be harmed by harder pelleting or by longer centrifugation times. Small changes usually cause no problem. However, some biological samples deteriorate if centrifuged too long, especially without refrigeration. And certain assays, which are sold in the form of kits, may be time-sensitive. When in doubt, follow the original instructions as closely as possible.

ROTORS AND THEIR USES



Horizontal Rotor

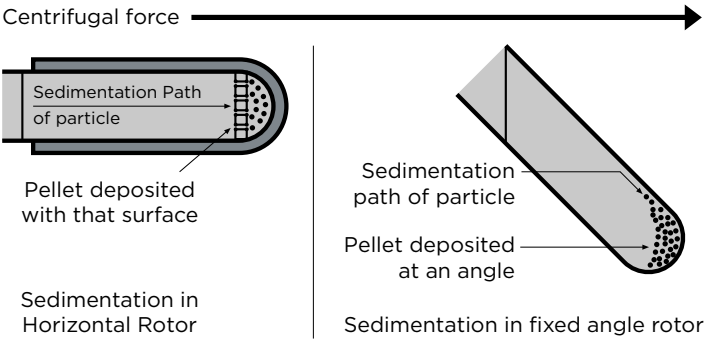


Fixed Angle Rotor

The two main types of rotors used in laboratory centrifuges: horizontal (also called swinging bucket) and fixed angle (or angle head).

Horizontal rotors are so-called because the buckets or racks which hold the centrifuge tubes are suspended in a manner which allows them to swing up into the horizontal plane when under the influence of a centrifugal field. Thus, when the centrifuge is operating, particles sediment along an unimpeded, radial path, away from the center of rotation, and deposit evenly on the bottom of the tube or other container. The flat upper surface of the sedimented material simplifies removal of the supernatant from a loosely packed pellet. By means of various adapters, more than one type or size of tube can be centrifuged together, provided the load is properly balanced. (Balancing is discussed in the next section.)

Fixed angle rotors hold the tubes at an angle to the axis of rotation. The angle varies with different rotors, somewhere between 25° to 40° being common. Although particles sediment along a radial path in these rotors also, they soon strike the opposite side of the tube where they slide down the wall to the bottom. The result is faster sedimentation than can be achieved in horizontal rotors which have a longer sedimentation pathlength. But because the bottom of the tube is not aligned with the direction of the centrifugal force, particles will collect partly along the side of the tube. This can make the collection of a loosely packed pellet somewhat more difficult than when a horizontal rotor is used.



Within these two categories of rotors, various models offer different combinations of capacity and maximum RCF attainable. Horizontal rotors, in particular, have accessories which suit them to a wide range of applications. The buckets suspended from the rotor yoke can carry large containers such as blood bags or bottles. Adapters are available for these buckets so that a number of small tubes can be run simultaneously for applications such as RIA. Horizontal rotors can also be equipped with racks or carriers, rather than buckets, suitable for spinning RIA tubes or micro-test plates.

When quick pelleting of small particles is required, fixed angle rotors should be used. Because of their design, these rotors are capable of higher speeds than the horizontal type. Sedimentation of larger particles, such as cells, protein precipitates, antigen-adsorbent complexes, urinary crystal, etc., can be done at lower speeds with horizontal rotors Maximum centrifugal force can be obtained with the latter if a wind-shielded version is used. (Wind-shielding improves rotor aerodynamics so that higher speeds are possible.) Density separation of cells is done best in a horizontal rotor of either type.

A BALANCED LOAD

In order for a rotor to run smoothly and safely at its operating speed, the load it carries must be balanced. Examples of correct and incorrect loading are shown in Figures 4 and 5 on the following pages. A rotor can be properly balanced by following some simple rules:

1. A rotor must *never* be run with buckets missing, although opposing buckets may be left empty.

2. All opposing loads must balance within a certain weight as specified by the centrifuge manufacturer's instruction manual.

3. If opposing buckets are run with a *partial* load of tubes in their adapters, these tubes must be arranged symmetrically, both with respect to the pivotal axis of each bucket and across the center of rotation (see Figure 3). With some partial loads, it may be difficult or impossible to achieve the correct symmetry in both sets of opposing buckets. The simplest solution is to fill one or more tubes of the same size with water, or a denser liquid if necessary, and use them to balance the load symmetrically.

Most centrifuges are equipped with an imbalance detector which turns the centrifuge off before any eccentric rotation caused by a load imbalance can damage the drive shaft or bearings. However, the improper distribution of tubes in carriers or adapters can cause poor separations even if the imbalance isn't severe enough to trigger this detector. In these situations, the buckets won't pivot to the required horizontal position during the run (see Figure 5), resulting in poor density separations or re-mixing of sedimented material during deceleration. Also, the possibility of tube breakage during the run is greatly increased when the buckets are not horizontal at operating speed.

You may notice that the centrifuge vibrates when the rotor is accelerating or decelerating at low speeds. This is normal, and occurs as the rotor passes through a so called critical speed range where any small vibrations are temporarily amplified. Your separations will not be disturbed during deceleration, because the centrifugal force is still high enough to stabilize them. However, you should not select an operating speed within the range where these exaggerated vibrations occur. Your instruction manual will tell you what speeds to avoid.

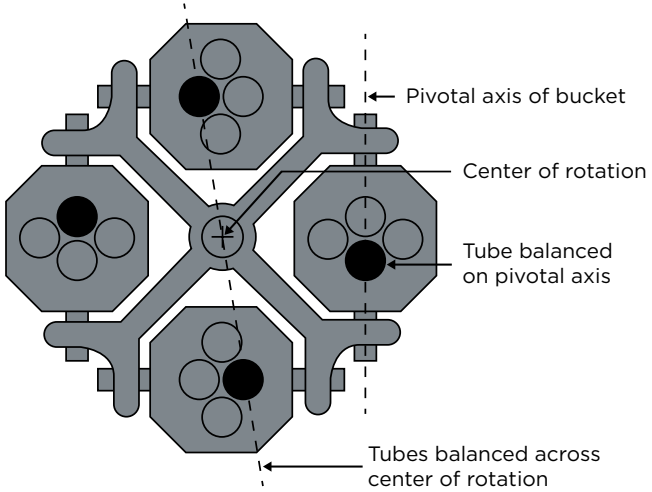


Figure 3. Correct Symmetry When Balancing a Partial Load – A Top View of a Horizontal Rotor

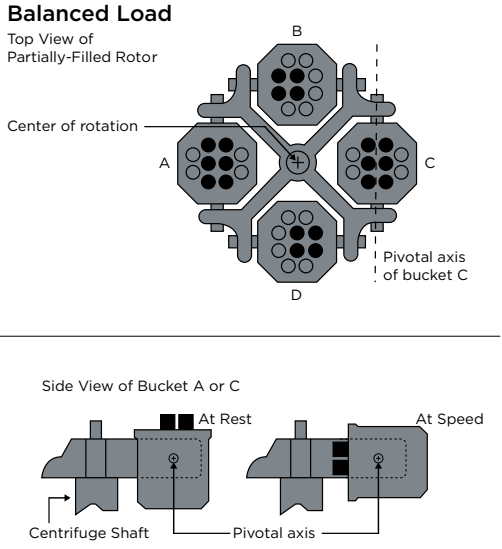


Figure 4. Example of a Balance Load

Assuming all tubes have been filled with an equal amount of liquid, this rotor load is balanced. The opposing bucket sets A-C and B-D are loaded with an equal number of tubes and are balanced across the center of rotation. Each bucket is also balanced with respect to its pivotal axis.

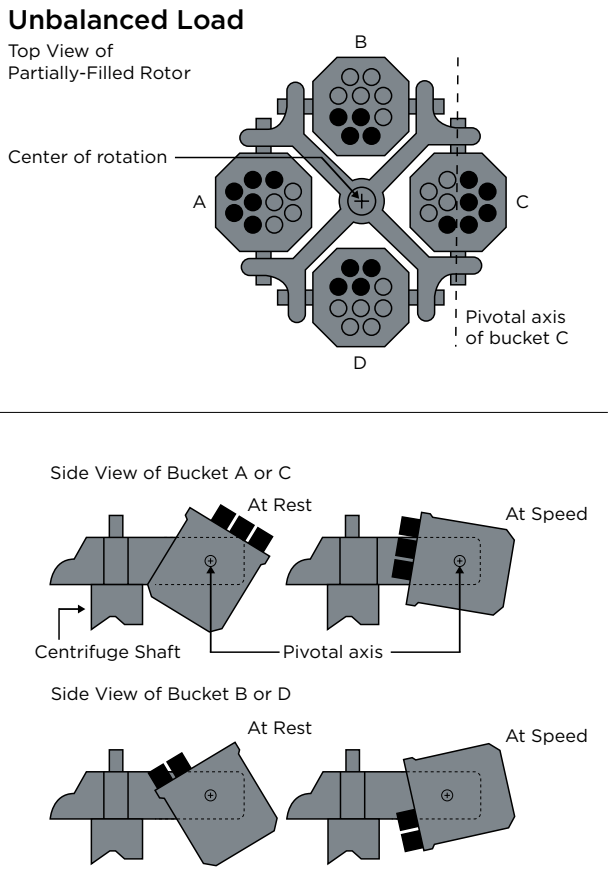


Figure 5. Example of an Unbalanced Load

Even if all the tubes are filled equally, this rotor is improperly loaded. None of the bucket loads are balanced with respect to their pivotal axes. At operating speed, buckets A and C will not reach the horizontal position. Buckets B and D will pivot past the horizontal. Also note that the tube arrangement in the opposing buckets B and D is *not* symmetrical across the center of rotation.

SOME PRECAUTIONS

AVOIDING ROTOR FAILURES

The centrifugal field which accelerates the separation process also exerts large forces on the rotor material. If a rotor fails, the centrifuge is severely damaged as well. For this reason, some simple precautions should be observed.

Rotors are designed to be run up to their maximum speed with a load of a specific weight. One should never attempt to run a rotor at a speed higher than the one designated by its manufacturer. Also, if high density solutions (greater than 1.2 g/mL, for instance) are used, the run speed must be reduced to prevent undue stress on the rotor. Consult your instruction manual for exact directions.

TUBE BREAKAGE

Glass tubes can break during centrifugation, due either to improper loading or inherent defects. Any glass fragments must be removed from the buckets, adapters, rubber liners, and rotor chamber before the next run is made. If you find gray dust, which results from sandblasting of the rotor chamber by glass particles, it must be cleaned up too. You should make several dry runs without samples, and clean the chamber between each run to be sure this dust is eliminated from the centrifuge.

CHEMICAL RESISTANCES

If you plan to centrifuge any uncommon solvents or solutions, consult your manual to be sure they are compatible with the various plastics and metals comprising the centrifuge, the rotor, the tubes, and other accessories. These same precautions must be observed with any solvents used for sterilization purposes. A table of 19 chemical resistances for common centrifuge materials is available from Beckman Coulter.

AEROSOL GENERATION

If any liquid is spilled on a rotor, it will be dispersed as a particulate mist when the centrifuge is run. Part of this mist will be fine enough to form a relatively stable aerosol which will tend to be dispersed throughout the laboratory. Such spills should be thoroughly cleaned up before running the centrifuge.

HANDLING HUMAN SAMPLES

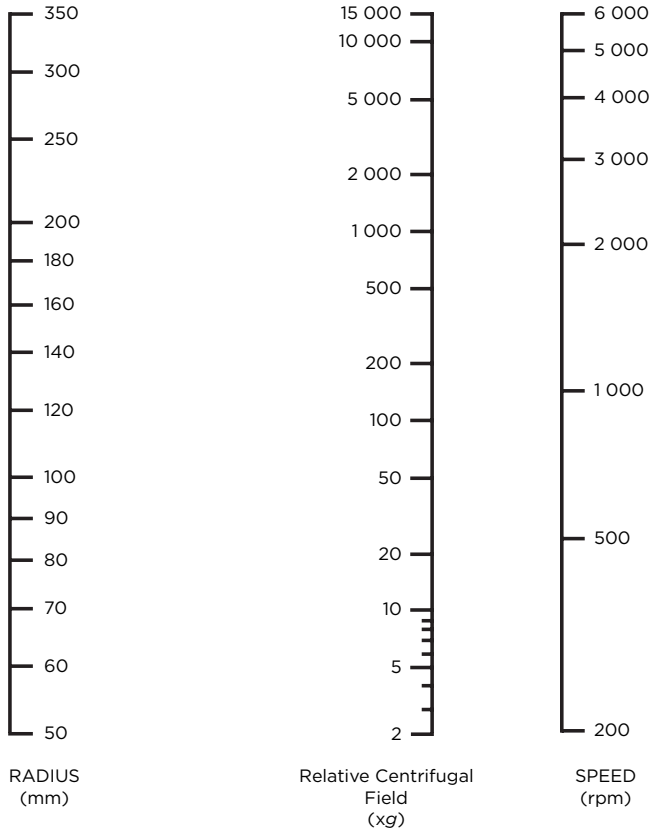
Human blood or blood components can transmit an infectious disease or virus if the patient or donor carries these. Blood should be handled with respect for this possibility during all laboratory manipulations, including centrifugation.

WHEN IN DOUBT, REFER TO YOUR INSTRUCTION MANUAL

From time to time, you'll have questions about the actual operation and maintenance of your centrifuge. The instruction manual provided with each instrument is designed to answer these questions. It should be read

before making your first run, and kept handy for future reference.

NOMOGRAM FOR SPEED SELECTION



The centrifugal forces at a given radius are a function of run speed. To obtain a desired rotor force, align a straightedge through known values in any two columns. Read the required value from the third column intersect. Typical radii are given in the preceding table of Rotor Specifications.

GLOSSARY

Some brief definitions of common terms relating to centrifugation are given here. Further discussion will be found on the page indicated after each definition.

Angle Heat Rotor – Another name for a fixed angle rotor.

Centrifugal Force – In a centrifugal field, the force which pulls a particle away from the center of rotation.

Density – Mass per unit volume.

Density Separation – A centrifugal separation process based on differences in density between particles.

Differential Centrifugation – A centrifugal separation process based on differences in size between particles.

Fixed Angle Rotor – A rotor in which the tubes are held at an angle.

Horizontal Rotor – A rotor in which the tubes are carried in buckets or racks that swing up to the horizontal position during centrifugation.

Maximum Radius – The radial distance from the center of rotation to the bottom of the rotor cavity in a fixed angle rotor, or the bottom of the bucket during centrifugation in the case of a horizontal rotor.

Near Vertical Tube Rotor – A rotor where tubes are held at a slight angle to the axis of rotation (typically 7 to 10 degrees). The slight angle of the rotor significantly reduces run times from fixed angles (with tube angles of 20 to 30 degrees) while allowing components that do not band under separation conditions to either pellet to the bottom or float to the top of the tube.

Pellet – the material sedimented to the bottom of the tube by centrifugation. Also called the sediment.

Relative Centrifugal Field – (abbreviated RCF). The ratio of a centrifugal field at a specific speed and radius to the earth's field of gravity. $RCF = 1.12r(RPM/1000)^2$ where r is the radius in mm, and RPM is the speed of rotation in rpm.

Sedimentation – The settling out of particles from a suspension in the earth's field of gravity. In the centrifuge this process is accelerated and the particles move away from the center of rotation.

Supernatant – The liquid above the sedimented material following centrifugation.

Swinging Bucket Rotor – another name for a horizontal rotor.

Vertical Tube Rotor – A rotor where tubes are held parallel to the axis of rotation. The short path length results in reduced run times.

BECKMAN COULTER CENTRIFUGES

Providing over 60 years of global leadership in centrifugation, Beckman Coulter Life Sciences designs, manufactures, sells, and services a complete line of centrifuge systems. By offering unique rotors and innovative bottles, tubes and accessories, coupled with advanced centrifugation software, Beckman Coulter delivers intelligent centrifugation solutions to laboratory science.

Our two highest performance families are the Optima Series Ultracentrifuges, offered in both floor and tabletop models, and the Avanti Series High-Performance and High-Capacity Centrifuges. Our continuum of centrifuge solutions also includes general purpose benchtop and microcentrifuges.

ULTRACENTRIFUGE - OPTIMA SERIES

Optima X Series

The Optima X series of ultracentrifuges feature a sophisticated on-board computer with intelligent eXPert software, easy-to-use touchscreen control, enhanced BioSafety*, remote monitoring and security and tracking features. The eXPert software provides optimized run methods, run simulation software, calculation tools, rotor and tube catalogs, automatic run records and more. All models are designed with quiet-drive technology (operates at less than 51dBA) and are energy efficient with regenerative braking, which returns energy to the local circuit, and thermoelectric cooling for low power consumption. Models include Optima XPN-100, XPN-90, XPN-80, XE-100, and XE-90.

Optima MAX Series

The Optima MAX Series tabletop ultracentrifuges include the Optima MAX-XP and the Optima MAX-TL. The Optima MAX-XP tabletop ultracentrifuge is the premium model and delivers fast run times with up to 150,000 RPM (2,500 revolutions per second) and is exceptionally quiet, producing half the sound output of previous Optima models. The user interface is intuitive, customizable, and available in an array of native languages, with control via a full-color touch-screen. Optional remote

monitoring and control of the system is also available. Not only does the Optima MAX-XP fit inside a standard BioSafety hood, but it can be ordered with HEPA filtration for enhanced safety. The Optima MAX-TL tabletop ultracentrifuge is the entry-level model, delivering optimum functionality and efficiency within a compact, quiet package. The MAX-TL can reach speeds of up to 120,000 RPM, and is compatible with existing Beckman Coulter TL-Series rotors and labware. It also offers multilingual software, full color LCD touchscreen and multi-level approach to BioSafety.

HIGH PERFORMANCE - AVANTI SERIES

Whatever your application, from simple pelleting to rate zonal separations, the Avanti JXN Series helps you gain traction on your experiments, whether you're relying on the Avanti JXN-26 to boost your productivity, or reaching speeds of up to 30,000 rpm while maintaining 4°C with the Avanti JXN-30.

Flexibility reaches a whole new level with the MobileFuge remote application for Avanti centrifuges. Users can easily monitor and control centrifuge functions via computer, using Virtual Network Computing (VNC) software or mobile devices using the custom MobileFuge app available for Apple® iOS and Android™ devices, allowing you to keep an eye on your centrifuge whether you are in the lab or across campus.

GENERAL PURPOSE BENCHTOP - ALLEGRA SERIES

The Allegra and Microfuge Series Benchtop Centrifuges provide excellent performance and versatility. Designed specifically with key applications in mind, the Allegra series offers high functionality in compact packages. Every piece of our equipment is engineered with planned durability, so that you can trust in reliable performance year after year, after year.

Designed with high throughput in mind, Allegra Series benchtops offer a max capacity up to 3.0 L, speeds up to 18,000 RPM, and are available in both refrigerated and nonrefrigerated options, which can save you precious time you can devote to other critical tasks. In addition, our comprehensive library of versatile rotors offer you options for a wide range of applications.

MICROFUGE SERIES

Our refrigerated Microfuge 20R and non-refrigerated Microfuge 20 models offer powerful g-forces for fast pelleting with a Relative Centrifugal Force (RCF) up to 20,627 x g with the FA241.5 rotor. The Microfuge 20 models have a maximum capacity of (36 x 1.5/2.0mL) with the BioCertified** fixed-angle rotor FA361.5. Reach speeds up to 15,000 RPM, save up to 10 user-defined programs and choose from four different rotor options with the Microfuge 20 Series. The Microfuge 20R precooling program precools samples fast, minimizing the time precious samples spend inside the microcentrifuge. The Microfuge 20R maintains 4°C at maximum speed for all rotors.

Microfuge 16 spins quietly at 16,163 x g for fast pelleting or isolation of DNA, RNA, proteins and viruses. In addition, it fits easily in the tightest of workspace environments with a height under 7 inches (17.6 cm) and a footprint measuring 8.9 by 10.5 inches (22.6 x 26.6 cm).

MULTI-LEVEL BIOCONTAINMENT FOR LABORATORY SAFETY

The Beckman Coulter BioSafe* Centrifuge Systems' unique multilevel approach to containment provides the most comprehensive solution to BioSafety. From innovative labware like the Aerosolve Canisters and HarvestLine System Liners to BioCertified rotors to centrifuges with HEPA filtration — the BioSafe Centrifuge Systems provide enhanced BioSafety.

ROTORS

Our extraordinary library of innovative rotors are designed, manufactured, and tested with our centrifuges as a system from the inside out to make sure you receive separations that continually exceed your expectations. The increased efficiency of our rotors can reduce run times. Many rotors are BioCertified, assuring you that they are safe. Whatever your application, we have the system to meet your need.

INNOVATIVE LABWARE

Since they're specially designed for innovative application solutions, our patented ultracentrifuge tubes deliver improved efficiencies, including Quick-Seal for versatility, g-Max for small volume at greatest efficiency,

konical for the most concentrated pellet and OptiSeal for the easiest sealing with no tools.

HarvestLine System Liners are disposable centrifuge bottle liners that provide a significant improvement in the centrifugation of biological material. They simplify sample pellet retention and storage after decanting by eliminating time-consuming manual scraping of harvested solids from labware, enhancing operator BioSafety. These liners are used with a selection of Avanti Series High Performance Centrifuge rotors.

*BioSafe and BioSafety are terms intended to describe the enhanced biocontainment features of our products.

**BioCertified is a term used to describe our products which have been tested and validated to demonstrate containment of microbiological aerosols by an independent third-party facility. Improper use or maintenance may affect seal integrity and, thus, containment.

For Beckman Coulter's worldwide office locations and phone numbers, please visit "Contact Us" at **beckmancoulter.com**

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