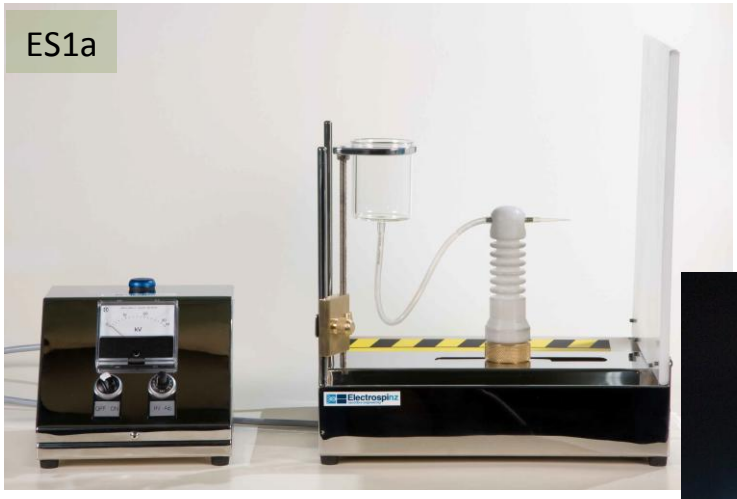
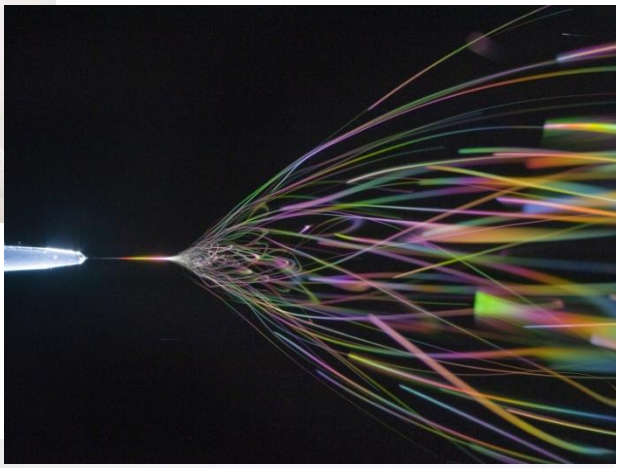
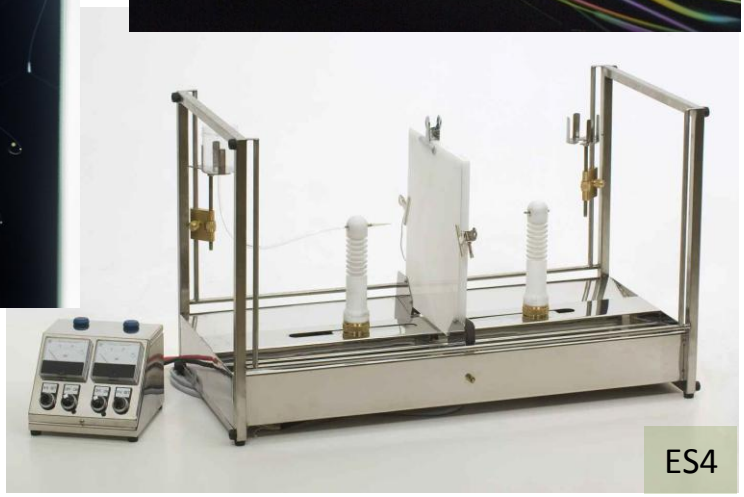
User Manual:

The electrospinning platforms ES1a and ES4







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1. Overview of the electrospinning platform

1.1. Purpose

The aim of this manual is to explain safe operating procedures for the electrospinning machine (ES4 and ES1a).

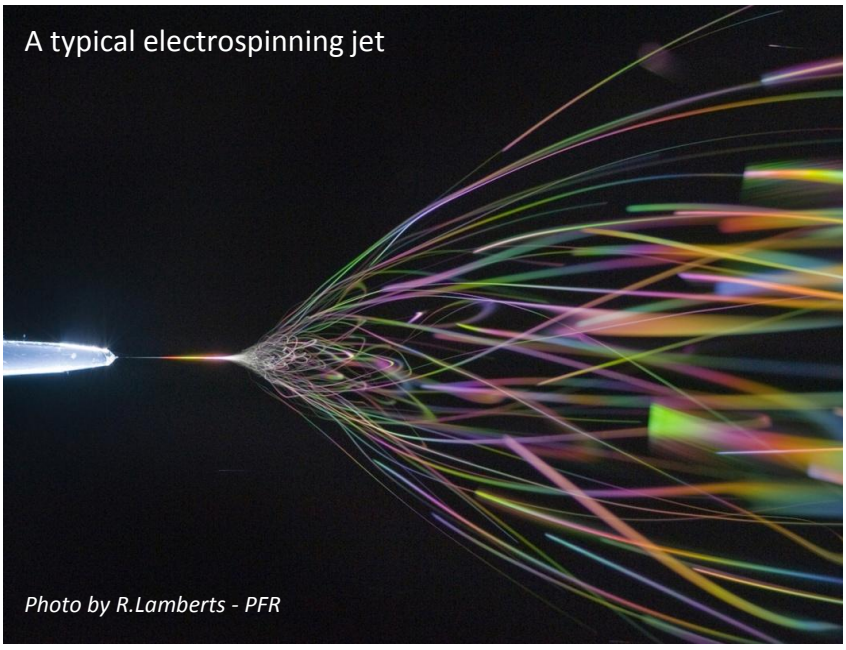
1.2. Principle

Electrospinning uses an electrical charge to draw very fine micro or nanofibres from a polymer in a liquid solution or melt. The process is non-invasive and does not require the use of coagulation chemistry or high temperatures to produce solid threads from solution. This makes the process particularly suited to the production of fibres using large and complex molecules.

When a sufficiently high voltage is applied to a liquid droplet, the body of the liquid becomes charged, and electrostatic repulsion counteracts the surface tension and droplet is stretched, and a Taylor cone appears, at a critical point a stream of liquid erupts from the surface, at the tip of the Taylor cone.

If the molecular cohesion of the liquid is sufficiently high, stream breakup does not occur (if it does, droplets are electrosprayed) and a charged liquid jet is formed. As the jet dries out in flight, the mode of current flow changes from ohmic to convective as the charge migrates to the surface of the fibre.

The jet is then elongated by a whipping process caused by electrostatic repulsion initiated at small bends in the fibre, until it is finally deposited on the grounded collector. The elongation and thinning of the fibre resulting from this bending instability leads to the formation of uniform fibres with nanometre-scale diameters.



1.3. Warnings

This is a research machine designed to allow maximum access to the process for research purposes. The only pieces that are significantly live during operation are the pipette tip, the transfer pipe and liquid within the reservoir.

The electrospinning machine runs at between 0-33,000 volts, the maximum current delivered by the machine is 0.3mA, a level of current much lower than that required for injuring a human. However, a shock from the machine is disagreeable – like a shock from static discharge.

1.4. Specifications

Description:

The ES1a and ES4 are designed to be used by competent operators in a laboratory environment, using an aqueous solution. Other solutions may be spun but the materials of the header tank, hose and spinning tip may need to be changed or adapted.

The ES1a, and ES4, is a one or two-part machine with a solid, easy to clean base. The constant head system is adjustable and has both coarse and fine adjustment. The moveable spinning head can be set from zero to 150mm for the ES1 and from zero to 200mm for the ES4, from the fixed target plane; this can be adjusted during operation. The power to the spinning head is adjustable from zero to + or -33,000 VDC from the separate control box.

Materials:

- **Base and Control Box are constructed from stainless steel**
- **Insulating materials are made of Polyoxymethylene (POM)**
- **Target plane 300mm x 350mm x 10mm is made of polyethylene (PE)**
- **Electrical connection fittings are made of brass**
- **Header tank is made of borosilicate glass**
- **Hose is made of Silicone rubber**
- **Spinning tip is made of high density polypropylene**

Power Supply:

Single phase 100 to 240 VAC, 1 amp maximum.
Power supply socket is a DIN standard fitting; most computer cords will fit this.

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2. Safety

2.1. Directions of use

High voltage power can present a serious risk of personal injury if not used in accordance with these safety instructions. All users of this equipment must have read and understood the contents of this manual before operation is begun.

The ES1a, and ES4, complies with the relevant New Zealand standards and has been constructed to comply with the electrical part of the BS EN 50 059: 1991 specification for hand-held spraying equipment for non-flammable material for painting and finishing. Although the output voltage can be as high as 33,000 Volts, the maximum output current cannot exceed 0.3mA. No conducting parts of the machine that are not earthed can be touched by the operator during normal operation, provided that these instructions are correctly followed.

Caution:

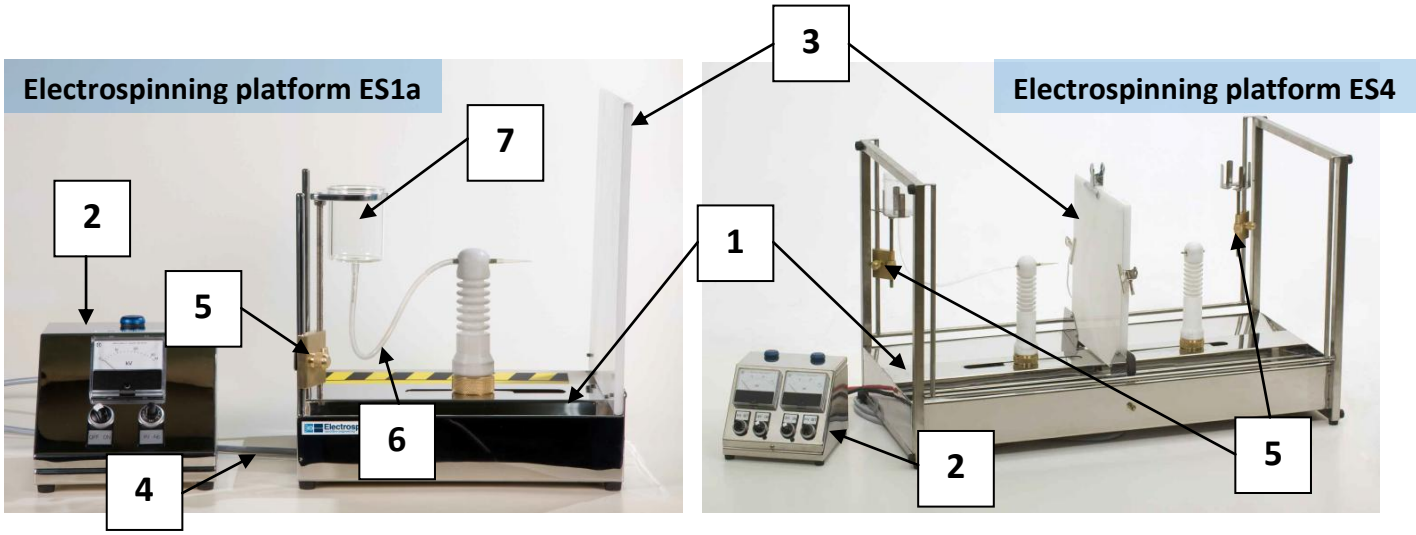
- Static charges may be present on insulated components, **even when the equipment is turned off.**
- Users **MUST ALWAYS** earth themselves by holding the metal frame of the ES1a or ES4 before touching any other part of the equipment.
- Electrospun fibres are charged during manufacture, this charge may be transferred to the depositing area. This charge is very low and provided the user is earthed, should be safe to handle.
- After the equipment is turned off, the high voltage system will take about **2 seconds to discharge**; do not touch the spinning bush during this time.
- Do not use this equipment unless the spinning tip and the feed hose are in place.
- Always ensure that there are no volatile gases near the ES1a or ES4 during operation as the spark from a static discharge could cause ignition.

When using hazardous chemicals:

- Read the Material Safety Data Sheet of each hazardous products;
- If there is no other way to be safe, use the personal protective equipment such as gloves, respiratory masks, protective glasses, lab coat and shoes.

3.General Guide

3.1. Parts checklist *(furnished with the spinning platform ES1a and ES4)*



	ES1a	ES4
1	1 ES1a spinning platform	1 ES4 spinning platform
2	1 ES1a Control Box	1 ES4 Control Box
3	1 300x350mm Target plane with 4 machine screws	1 300x350mm Target plane with 4 machine screws
4	1 Power cable	1 Power cable
5	1 Constant Head system	2 Constant Head system
6	2m Hose (to be cut to appropriate length to be use)	2m Hose (to be cut to appropriate length to be use)
7	2 Glass Header tank	2 Glass Header tank
8	1 Toolbox containing 1x Allen key set, 1x 10mm spanner, 1x 11mm spanner	1 Toolbox containing 1x Allen key set, 1x 10mm spanner, 1x 11mm spanner

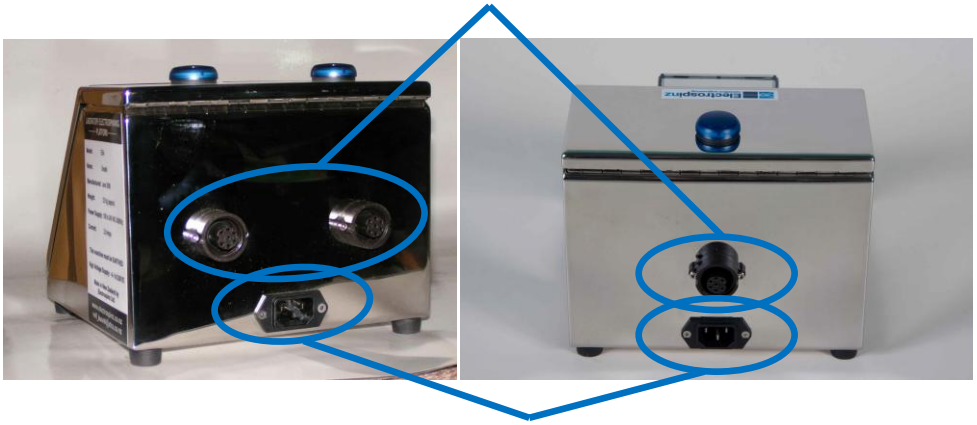
3.2. Initial Assembly

A. **Unpack and check** that the parts are all present.

B. **Remove** the four machine screws and **mount** the target plane to the end of the spinning platform (in the middle for ES4), **do not over tighten the screws**.

C. **Install** the constant head system as shown.

D. **Plug** the spinning platform lead into the back of the control box.

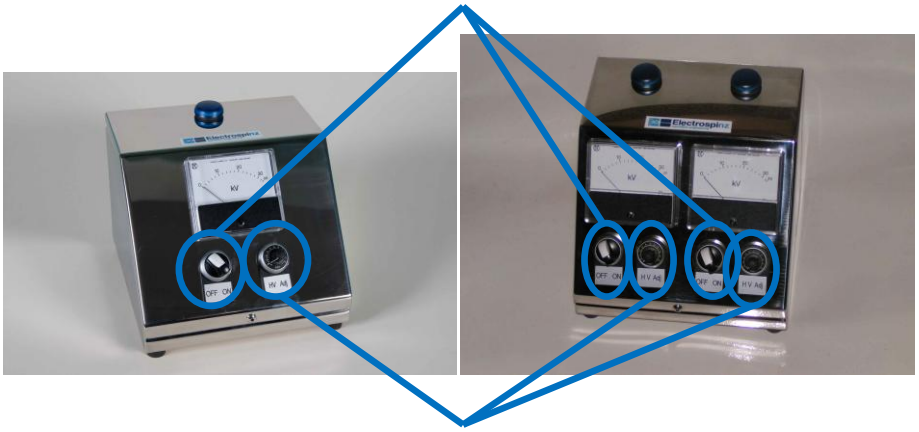


E. **Plug** the power cable into the back of the control box, and to the power supply.

3.2.1. The Assembly Test

F. **Check** that the earthed power outlet has a good earth by **plugging in** the power lead with the switch OFF and **checking** for Voltage to another earthed point. **This check should be repeated each time the ES1a is used, to keep the power supply.**

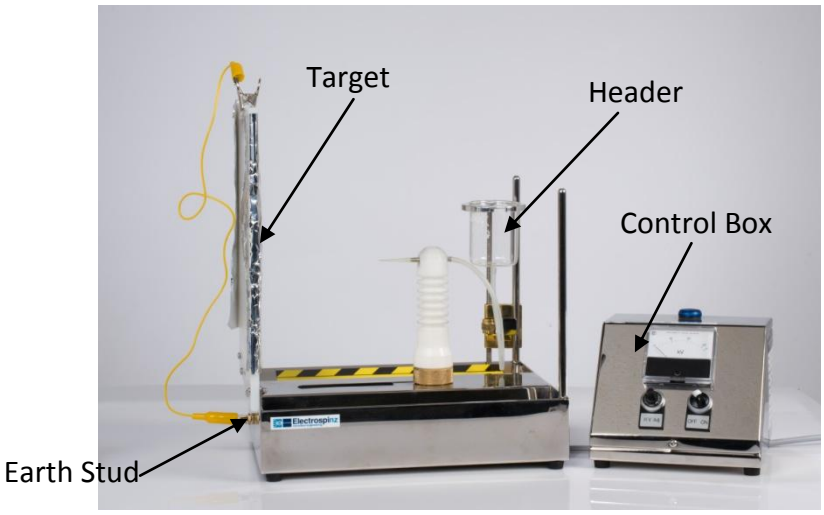
G. **Turn on** the power at the wall, **ensure** that the HV Adj. Knob is turned to Zero and **turn on** the ES1a, the blue light on top of the control box should light up.

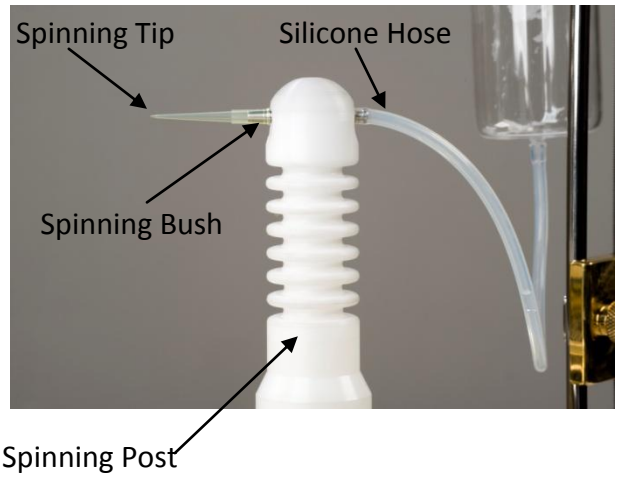


H. **Turn** the HV Adjuster knob **slowly** to full power **and back**, the meter should smoothly move between 0 and 33kV.

I. **Turn off** the ES1a or the ES4, it is ready to use.

3.3. Places of the other elements needed for electrospinning





3.4. Operation

1. **Perform the previous assembly test F. to I.**

2. **Place** the glass header tank between the tongs of the constant head system.

3. **Insert** the spinning bush at the top of the spinning post.
4. **Connect** the hose from the header tank to the spinning bush.

5. **Insert** the spinning tip over the spigot on the other side of the spinning bush.

6. **Place** a collector on the target, such as an aluminium foil or a metallic plate.

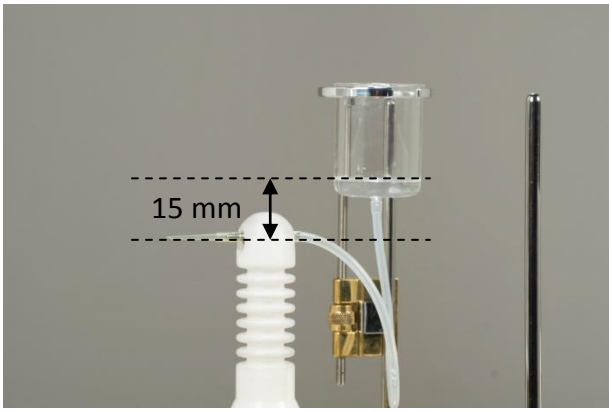
7. **Earth the target area**: connect the target to the ES1a or ES4 metallic platform. If this is not done then the fibres will be drawn to the nearest earthed thing. This is not necessarily the ES1a or ES4; it may be any structure within reach.

8. **Pour** the prepared polymer into the header tank.

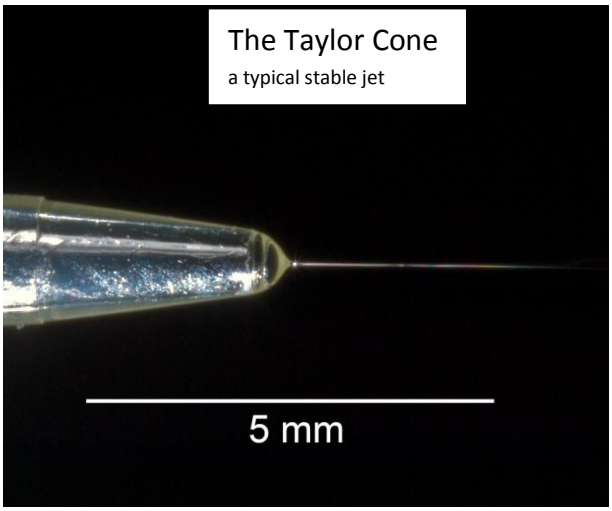
9. **Raise** the header tank to allow the liquid to flow to the tip of the spinning needle, with the course or manually.

10. **Maintain** the header tank to hold a small droplet of polymer at the spinning tip. A piece of paper towel may be placed on the ES1a or ES4 bed between the spinning tip and the target plane to assist with cleaning.

11. When the polymer is seen to be almost at the spinning tip **lower** the header tank to provide a head of about **15mm** above the spinning tip. This will need to be adjusted once spinning has begun.



12. With the HV Adj. knob turned to zero, **turn on the switch**. While watching closely to the tip of the electrospinning needle; **raise the voltage** until the **Taylor cone** appears this is normally visible with the naked eye. Normally only a very slight increase in voltage will initiate the spinning process.



If spinning is continued too long then the build up of fibre on the target can be enough to insulate the target and fibres may be deposited in other areas.

3.5. Maintenance

Cleaning

A. Remove the header tank, hose and spinning tip. Move these to the cleaning area.

B. Remove the spinning bush; use the 10mm spanner if required.

C. Do not remove the brass spinning bush holder!

D. The spinning bush is made from stainless steel and should be thoroughly washed and dried before reassembly.

E. The spinning tip may be cleaned but is designed as a disposable item.

F. Clean the base of the machine with a damp cloth or a cloth dampened with a little solvent. Be careful with solvents around the plastic components as these may be damaged by some solvents.

G. Reassemble in the reverse order, be careful not to over tighten the nut on the spinning bush, finger tight is usually enough.

Servicing

The ES1a and ES4 have been designed to be serviced without returning it to Electrospinz Limited.

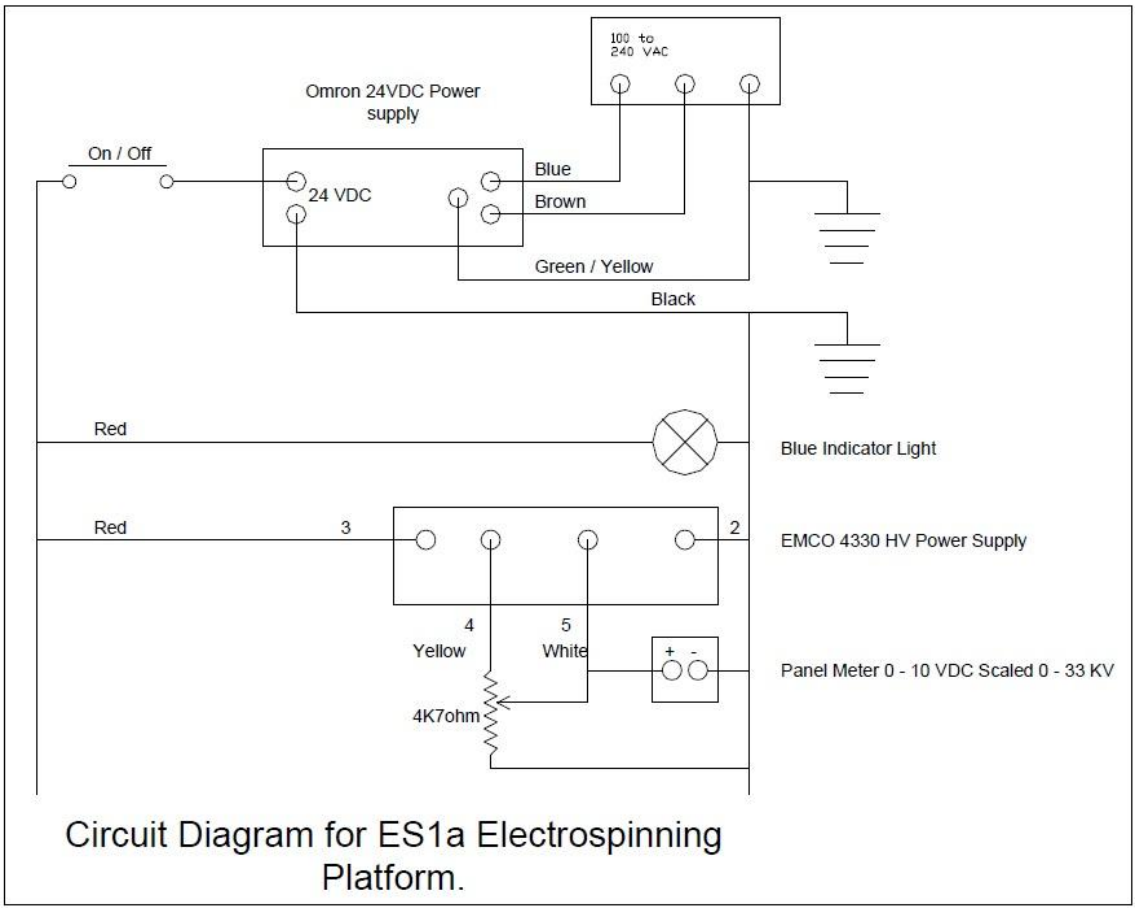
The electrical system must be serviced only by qualified personal and must be maintained in compliance with the relevant local legislation. Replacement components are available worldwide and should be obtained locally.

The mechanical components should be serviced by a competent person, any required special parts can be ordered from Electrospinz Limited.

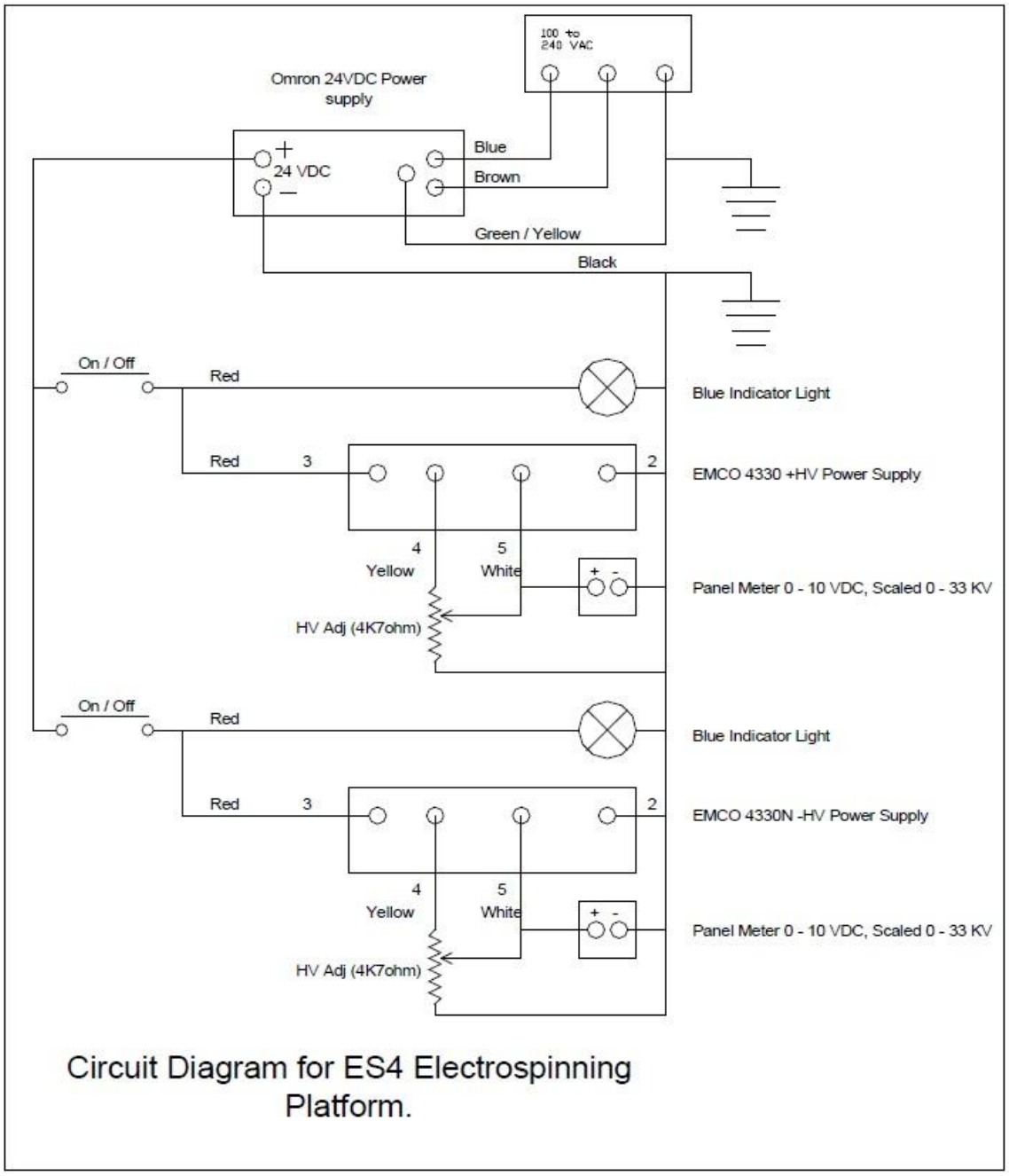
Circuit Diagram

Any servicing of the electrical system must be done by a qualified person in accordance with local requirements.

Wire numbers shown are for the Plug, socket, multi-core cable and HV power supply.



Circuit Diagram for ES1a Electrospinning Platform.



Circuit Diagram for ES4 Electrospinning Platform.

FAQ

How do I make up a solution of PVOH?

Polyvinyl Alcohol (PVOH) is soluble in water, but you should heat the distilled water to 60°C, and the powdered polymer (7-8wt %) should be stirred in very gradually to avoid the formation of lumps.

What can I use for a target?

Domestic aluminium foil works very well and sets of identified sample plates are available. Handle with gloves to avoid the transfer of grease and moisture from your hands. The target will need to be connected to earth through any part of electrospinner chassis, or the earth stud.

Can I use a syringe pump?

If you wish – the Electrospinz platform works by the constant pressure feed header tank with a wide range of polymers and solvent, but if you are working with an exceptionally viscous material, a syringe pump may be the answer. The pump can be connected through the spinning bush and pipette in the normal way.

What is the rate of deposition?

The rate is dependent on your choice of polymer system, but will decline with time, as the deposited fibre acts as an insulator, and allows a charge to build up on the target, The PVOH supplied will initially deposit at about 140µg/s after about 10 minutes.

Why doesn't the machine need an enclosure to be safe?

The Electrospinz machines are designed to have an intrinsic low capacitance. This is achieved by minimising the amount of metal surfaces that are charged by the power supply and the bonding to earth of all the metal surfaces of the machine. Good bond continuity is ensured by welding the component parts of the structure together. These design principles result in a machine capacitance of less than 10pF. Surrounding the machine with an insulating cabinet would increase the capacitance of the system.

Low machine capacitance is an important safety feature for the following reasons. When the machine capacitance (>10pF) is considered in connection with a human body, resistance of approximately 500 ohms (IEC 2005), this means the capacitive charge will discharge in under a millisecond leaving only the continuous supply capacity of the power supply to contend with in terms of risk of ventricular fibrillation (disruption of the activity of the heart). - *Cf. Appendix II:Why doesn't the machine need an enclosure to be safe?*

Glossary

- **Aligned fibres:** electrospun nanofibres which are parallel to each other.

- **(Applied) Voltage/Potential Difference:** The voltage applied to the solution via the control box. A typical voltage used for electrospinning is 10kV.

- **Control Box:** regulates the applied voltage and therefore the electrospinning process.

- **Deposition Process:** how the fibres are depositing on the target.

- **Earth Stud/Electric Current Collector:** connected to the earth, this device allows the current to circulate, and therefore, electrospinning to occur. This system is also designed to electrically discharge each metallic part of the platform is an important safety part of the machine.

- **Electrospinning:** The operation of creating nanofibres from a polymer dissolved in a solution by applying a voltage to that liquid.

- **Electrospinning Jet:** the jet formed by the liquid at the tip of the needle, between the Taylor cone and the whipping instability.

- **Laboratory Electrospinning Platform:** the name of the machine for electrospinning. “platform” indicates that the machine is designed to be modified for research purposes.

- **Electrospun nanofibres:** nanofibres which are created through an electrospinning process. Nanofibres are considered to be less than 100nm in diameter.

- **Electrospraying:** the operation of creating droplets with a nano-size through a similar process used for electrospinning.

- **Feed Pipe/Silicone Pipe/Feed Hose:** a plastic hose used to connect the reservoir to the spinning tip via the metallic spinning bush.

- **Flow Rate/ Mass Flow Rate:** The flow speed of the liquid, effectively the spinning speed of the process.

- **Fluid Pressure:** Pressure applied to the fluid to regulate the flow, and therefore, stabilize the electrospinning process. This can be controlled in increasing or decreasing the height of the Header Tank.

- **Grounded Collector/Target Substrate/Grounded Electrode:** the object used to collect the fibres; it may different shapes according to the kind of fibres wanted: a simple metallic plate or aluminium foil results in the creation of random fibres but a metallic wire frame results in the creation of aligned fibres. This collector must be connected to the earth to avoid charge accumulation.

- **High Voltage Electric Current:** The electric current that circulates between the spinning tip and the grounded collector. The maximum current which can be produced is under 0.33 mA. (See FAQ: Why doesn't the machine need an enclosure to be safe?)

- **Mass Deposition Rate:** The mass of fibres produced within a certain amount of time.

- **Magnetisation:** While using a metallic plate as a collector, using a magnet to keep the plate vertical will be useful. However, during the process, the plate will acquire a certain magnetisation that may interfere with the weighing process and misrepresents the real amount of fibres which have been deposited on the plate. Using a demagnetizer after electrospinning can prevent interferences while weighing the plate. This effect is only noticeable when using a 4 figure balance.

- **Nanofibres:** Fibres which diameter of less than 100 nanometres.

- **Porous surface and smooth fibres:** Nanofibres can have varying surface's morphologies for example the fibre surface may be pitted or smooth.

- **Removable Spinning Bush/Metallic Connector:** This element makes the connexion between the silicone hose and the spinning tip. It is connected to the high voltage supply.

- **Reservoir/Header Tank:** contains a certain amount of liquid and by varying the height of the reservoir controls the pressure or head of the flowing liquid.

- **SEM (Scanning Electron Microscope):** A type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and

composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometre.

- **Spinning Post or Electrode/High Voltage Electrode:** This part of the electrospinning platform keep the spinning bush and tip straight at a certain height aligned with the target. An electric wire is inside making the contact between the high voltage supply and the metallic connector, allowing the current to circulate.

- **Spinning Tip or Needle/Spinneret:** A conic tube with a very small exit at the tip, reducing considerably the flow of liquid allowing adjustments to the flow just by modifying the height of the header tank. It is positioned at the tip of the metallic connector. A micropipette tip or hypodermic syringe needle is often used.

- **Stable or continuous jets:** The stable part of the jet starts with a Taylor cone at the tip of the spinning needle. To achieve this, it is necessary to adjust the flow of liquid: if it is too quick, there will be a large droplet at the tip of the needle and the jet will not be continuous, if it is too slow, there will be a too small Taylor cone and the jet will not be continuous either. It is also possible to modify the tension applied to the fluid to obtain the Taylor cone, the higher the voltage will be, the higher the fluid consumption and flow rate will be.

- **Straight Jet/Axisymetric Jet:** The straight jet is a jet usually formed after the Taylor, before it begins to whip. This or those jet(s) is/are more or less longer depending in the parameters: the kind of solution used, the distance between the needle tip and the collector, the kind of collector and the applied voltage.

- **Surface tension:** The surface tension of a liquid is an important parameter while doing electrospinning. It is a contractive tendency of the surface of a liquid that allows it to resist an external force. This property is caused by cohesion of similar molecules, and is responsible for certain of liquids' properties. Therefore it is a useful parameter to know while creating solutions for electrospinning. Surface tension has the dimension of force per unit length or of energy per unit area.

- **Taylor Cone:** The cone observed at the tip of the spinning needle when high voltage is applied to the liquid, it is apparent as a deformation at the end of the liquid meniscus at the spinning tip. The apex of the cone is the point of ejection of the liquid stream what forms the jet. The cone is named after Sir Geoffroy Ingram Taylor (1886 – 1975) who first described it.

- **TCD (Tip to Collector Distance):** It's the distance between the spinning tip and the grounded collector, a typical TCD used for electrospinning is 10 cm.

- **Uniform fibres:** fibres are uniform when they have the same characteristics: diameter, alignment, and morphology.

- **Whipping or Bending Instability/Whipping Envelope:** During its flight, the jet is drying out and at a variable distance from the needle, the jet starts to whip and bend until it arrives at the collector. At its arrival, the jet is ideally only composed by the polymer; the solvent has all been lost in flight. Strictly speaking the flight path of the jet is an expanding helix, but this is commonly called the whipping instability.

4. Appendix

Appendix I - How to specify a ventilation system when using hazardous solvents?

Some solvent and diluents systems used in electrospinning are hazardous by contact or inhalation. To limit any hazards caused by the normal evaporation rate of the solvent to the atmosphere, it is recommended to use a lid on the header tank – usually a watch glass.

The Electrospinz machine is designed to fit inside standard laboratory fume cupboards. This is the recommended method of limiting operator exposure to solvents fumes. It may be necessary to switch off the fume cupboard ventilation during spinning to avoid the fibres being sucked away by the ventilation fan. The fume cupboard door should therefore be kept closed during spinning.

The laboratory ventilation system should be checked if such solvents are used. If you do not have access to a fume cupboard, you should assess if the ventilation in your laboratory is adequate.

To do this you need to know the safe exposure limit of the solvent. This can be found in the Material Safety Data sheet for the solvent. It is also important to know the volume of the room where the electrospinning will occur.

As an example, we will consider the use the Hexafluroisopropanol in a room with a volume of 140 m^3. The exposure limit of this solution is 2.5 mg/m^3, so the limit will be reached when 3500 mg of solvent has evaporated. (140 m^3 * 2.5mg/m^3)

What we need to know next, is the amount of time necessary to reach that limit, for that purpose we can use the evaporation rate of PVOH in water which is 60 mg/h, during electrospinning.

Then we can calculate the amount of time to reach the limit:

$$t = \frac{350\ mg}{60\ mg/h} = 5.83\ h = 5h49\ \min 48s$$

But this evaporation rate is true only for the PVOH so we must apply safety coefficients to that calculation, x5 or x10 are a safe allowance.

With an evaporation rate multiplied by 5, we find this result:

$$t_{10}\frac{350}{60 \times 10} = 1.17h = 1h10\ min$$

With an evaporation rate of 10, we find this result:

$$t_5 = \frac{350}{60 * 5} = 0.58h = 35\ min$$

Those times means that the room air would need to be completely renewed within 1h or 35 minutes depending on the safety level required. Depending on the hazards and the amount of product used, it would be better to apply the safety rating of 5 or 10. Even if the spinning platform is completely isolated, it is strongly recommended to always wear a respirator when using these kinds of hazardous chemicals.

Appendix II - Why doesn't the machine need an enclosure to be safe?

An Electrospinz machine, at maximum current output (short circuit conditions) cannot produce enough current to disrupt the action of the heart [1]. It can be calculated that for the supply to produce enough energy to disrupt the activity of the heart, the victim [2] would need to be in contact with a live part of the machine for more than five hours [3].

[1] Minimum current required to produce Ventricular Fibrillation irrespective of voltage

$$I^2 t = 2 \times 10^{-3} \mathrm{A^2 s}$$
$$I^2 \times 0.01\mathrm{s} = 2 \times 10^{-3} \mathrm{A^2 s}$$
$$I \geq \sqrt{\frac{2 \times 10^{-3} \mathrm{A^2 s}}{0.01\mathrm{s}}}$$
$$\boldsymbol{I \geq 0.4472 \mathrm{A}}$$

Note: The EMCO high voltage power supply cannot supply more than 0.33mA or 0.33×10^{-3}A.

[2] There may be potential danger to those with a very weak heart or a pacemaker; users who fall into either of these categories are advised to consult their doctor as to the likely risk in their particular case.

[3] For an impulse current *I* Amps of short duration t < 10ms through the body, the principal factor for the initiation of ventricular fibrillation is the value of $I \times t$ (Intensity x time) or $I^2 t$ (IEC 2007). At high applied voltages, the resistance of the adult body (left hand to right hand) is at least 575 ohms for 95% of the population (IEC 2005). Note that the figures quoted for resistance are typical for a healthy adult, and refer to the resistance measured through dry skin, if the skin is punctured or wet, then the resistance is reduced.

The IEC gives a threshold value of Specific Fibrillation Energy, for a 1 ms current impulse, of 2×10^{-3} A^2s. Below this threshold there is no evidence of fibrillation. The Specific Fibrillation Energy can be regarded as the energy dissipated per unit resistance of the body through which the current flows. Note that 'specific' here means 'per unit resistance' rather than 'per unit mass'.

Time required producing Ventricular Fibrillation with EMCO supply:

$$I^2t = 2 \times 10^{-3}\text{A}^2\text{s}$$
$$(0.33 \times 10^{-3}\text{A})^2 t = 2 \times 10^{-3}\text{A}^2\text{s}$$
$$t = \frac{2 \times 10^{-3}\text{A}^2\text{s}}{(0.33 \times 10^{-3}\text{A})^2}$$
$$\boldsymbol{t = 5.1\text{hours}}$$

References

IEC 2007. IEC/TS 60479-2:2007. Effects of human beings and livestock – Part 2: Special aspects.
IEC 2005. IEC/TS 60479-1:2005. Effects of human beings and livestock – Part 1: General aspects.

Appendix III – Electrospinnable materials and conditions

Synthetic Polymers			
Polyethylene oxide (PEO)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
Water, Acetone *(Megelski et al., 2002)* Chloroform, Ethanol, N,N – Dimethylformamide (DMF) *(Son et al., 2004a)* 0.5 M Acetic Acid *(Bhattarai et al., 2005)* Water/Methanol (90:10) *(Kessick and Tepper, 2004)* Water/Ethanol (60:40) *(Reneker et al., 2000)*	Concentration: ~10% *(Megelski et al., 2002)* Molecular Weight: ~400,000 *(Deitzel et al., 2001a)* Voltage: 10 kV – 20 kV *(Son et al., 2004a)* Distance: ~15 cm *(Deitzel et al., 2001a)* Electric Field: 0.5 kV/cm – 1 kV/cm *(Shin et al., 2001a)*	Conc.: 1% *(Doshi and Reneker, 1995)* - 10% *(Deitzel et al., 2001b)* M_w: 300,000 *(Sun et al., 2006)* -2,000,000 *(Shin et al., 2001b)* Voltage: 1 kV *(Sun et al., 2006)* – 30 kV *(Kidoaki et al., 2005)* Distance: 5 cm *(Kidoaki et al., 2005)* -40 cm *(Theron et al., 2005)* Electric Field: 0.2 *(Doshi and Reneker, 1995)* – 3.2 kV/cm *(Yarin and Zussman, 2004)*	*(Bhattarai et al., 2005, Deitzel et al., 2001a, Deitzel et al., 2001b, Doshi and Reneker, 1995, Fong et al., 1999, Hohman et al., 2001, Huang et al., 2003, Kessick et al., 2004, Kessick and Tepper, 2004, Kidoaki et al., 2005, Megelski et al., 2002, Reneker et al., 2000, Shin et al., 2001a, Shin et al., 2001b, Son et al., 2004a, Spivak et al., 2000, Sun et al., 2006, Theron et al., 2005, Wang et al., 2004, Yarin et al., 2001, Yarin and Zussman, 2004)*

Polyvinyl alcohol (PVOH)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
Water *(Koski et al., 2004)* Ethanol/Water (1:1) *(Theron et al., 2004)* Aqueous Acetic Acid *(Duan et al., 2006)*	Concentration: ~ 8% *(Wang et al., 2006b*) Molecular Weight: ~ 80,000 *(Guan et al., 2003b)* Voltage: ~ 20kV *(Ding et al., 2002)* Distance: ~ 10cm *(Son et al., 2005)* Electric Field: ~ 1.5 kV/cm *(Duan et al., 2006)*	Conc.: 4.1% *(Shao et al., 2003)* - 18% *(Ding et al., 2002)* Conc.: $2.8e^{-7}$ mol/L *(Ding et al., 2002)* – $2.9e^{-6}$ mol/L *(Lee et al., 2004)* M_w: 10,000 *(Theron et al., 2004)* -185,000 *(Koski et al., 2004)* Voltage: 5kV *(Zhang et al., 2005)* – 100kV *(Theron et al., 2004)* Distance: 3.5 cm *(Morozov et al., 1998)* - 25 cm *(Wang et al., 2004)* Electric Field: 0.3 kV/cm *(Zhang et al., 2005)* – 4 kV/cm *(Lee et al., 2004)*	*(Ding et al., 2002, Ding et al., 2004, Duan et al., 2006, Guan et al., 2003a, Guan et al., 2003b, Guan et al., 2003c, Koski et al., 2004, Lee et al., 2004, Morozov et al., 1998, Ohkawa et al., 2004, Ristolainen et al., 2006, Shao et al., 2003, Shenoy et al., 2005b, Son et al., 2005, Theron et al., 2004, Wang et al., 2006b, Wang et al., 2004, Yao et al., 2003, Zhang et al., 2005)*

Polystyrene (PS)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
N,N – Dimethylformamide, Toluene *(Megelski et al., 2002)* Carbon Disulfide (CS2) *(Eda et al., 2007b)* Chloroform, Tetrahydrofuran (THF), Methylethylketone *(Jarusuwannapoom et al., 2005)* Acetic Acid *(Wannatong et al., 2004)*	Concentration: ~20% *(Shin et al., 2005)* Molecular Weight: 200,000 – 300,000 *(Jarusuwannapoom et al., 2005)* Voltage: ~30 kV (Eda et al., 2007b) Distance: ~15 cm (Wang et al., 2006a) Electric Field: ~1 kV/cm *(Sundaray et al., 2004)*	Conc.: 2.5% *(Eda et al., 2007a)* - 35% *(Casper et al., 2004)* Conc.: $1.4e^{-8}$ mol/L *(Eda et al., 2007a)* – $1.7e^{-5}$ mol/L *(Casper et al., 2004)* M_w: 4,000 *(Wang et al., 2006a)* – 1,880,000 *(Wang et al., 2006a)* Voltage: 3 kV *(Sundaray et al., 2004)* – 30 kV *(Wannatong et al., 2004)* Distance: 3 cm *(Sundaray et al., 2004)* – 35 cm *(Casper et al., 2004)* Electric Field: 0.14 kV/cm *(Megelski et al., 2002)* – 3 kV/cm *(Eda et al., 2007b)*	*(Casper et al., 2004, Eda et al., 2007b, Eda et al., 2007a, Fong and Reneker, 1999, Jarusuwannapoom et al., 2005, Megelski et al., 2002, Shenoy et al., 2005a, Shin et al., 2005, Sundaray et al., 2004, Wang et al., 2006a, Wannatong et al., 2004)*

Polyacrylonitrile (PAN)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
N,N – Dimethylformamide (DMF) *(Smit et al., 2005)*	Concentration: 10% *(Kim and Yang, 2003)* Molecular Weight: ~75,000 *(Qin et al., 2004)* Voltage: 10-25 kV *(Kim and Yang, 2003)* Distance: ~16cm *(Samatham and Kim., 2006)* Electric Field: ~1.7 kV/cm *(Ko et al., 2003)*	Conc.: 4% *(Qin et al., 2007)* - 14% *(Qin et al., 2005)* Conc.: $3.8e^{-4}$ mol/L *(Sutasinpromprae et al., 2006)* – $3.2e^{-3}$ mol/L *(Sutasinpromprae et al., 2006)* M_w: 55,000 *(Sutasinpromprae et al., 2006)* – 210,000 *(Smit et al., 2005)* Voltage: 5 kV *(Qin et al., 2004)* – 40 kV *(Qin et al., 2007)* Distance: 10 cm – *(Sutasinpromprae et al., 2006)* 30 cm *(Sutasinpromprae et al., 2006)* Electric Field: 0.3 kV/cm *(Samatham and Kim., 2006)* – 3 kV/cm *(Sutasinpromprae et al., 2006)*	*(Ko et al., 2003, Smit et al., 2005, Sutasinpromprae et al., 2006, Qin et al., 2007, Kim and Yang, 2003, Samatham and Kim., 2006, Qin et al., 2004, Qin et al., 2005)*

Biopolymers			
Polycaprolactone (PCL)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
Chloroform/Methanol (3:1) *(Dalton et al., 2005)* Toluene/Methanol (1:1), Dichloromethane/Methanol (3:1), Acetone *(Theron et al., 2004)*	Concentration: ~10% *(Theron et al., 2004)* Molecular Weight: ~80,000 *(Zhang et al., 2004)* Voltage: ~15 kV *(Dalton et al., 2005)* Distance: ~12 cm *(Zhang et al., 2004)* Electric Field: ~1 kV/cm *(Duling et al., 2008)*	Conc.: 5% *(Lee et al., 2008)* - 12% *(Fridrikh et al., 2003)* Conc.: $2.5e^{-4}$ *(Lee et al., 2008)* - $1.3e^{-3}$ *(Zhang et al., 2004)* M_w: 80,000 *(Theron et al., 2004)* – 200,000 *(Lee et al., 2008)* Voltage: 12 kV *(Theron et al., 2004)* – 20 kV *(Lee et al., 2008)* Distance: 10 cm *(Lee et al., 2008)* – 15cm *(Dalton et al., 2005)* Electric Field: 1 kV/cm *(Dalton et al., 2005)* – 2 kV/cm *(Lee et al., 2008)*	*(Dalton et al., 2005, Fridrikh et al., 2003, Theron et al., 2004, Zhang et al., 2004, Lee et al., 2008, Duling et al., 2008)*

Polylactic acid (PLA, PLLA, PDLA)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
N,N – Dimethylformamide (DMF), N,N – Dimethylformamide (DMF) / Methylene chloride *(Zong et al., 2002)* Dichloromethane *(Shenoy et al., 2005a)* Dichloroethane, Chloroform *(Zeng et al., 2003a)*	Concentration: ~10% *(Zeng et al., 2003a)* Molecular Weight: ~109,000 *(Zong et al., 2002)* Voltage: ~25 kV *(Ko et al., 2003)* Distance: ~15 cm (*Zong et al., 2002)* Electric Field: ~2 kV/cm *(Zong et al., 2002)*	Conc.: 3% *(Shenoy et al., 2005a)* - 40% *(Zong et al., 2002)* Conc.: $4.5e^{-5}$ *(Shenoy et al., 2005a)* – $4.0e^{-3}$ *(Zong et al., 2002)* M_w: 48,000 *(Zeng et al., 2003a)* – 670,000 *(Shenoy et al., 2005a)* Voltage: 20 kV *(Zong et al., 2002)* – 41 kV *(Zeng et al., 2003b)* Distance: 15 cm *(Ko et al., 2003)* – 20 cm *(Zeng et al., 2003b)* Electric Field: 0.75 kV/cm *(Zeng et al., 2003a)* – 2 kV/cm *(Zeng et al., 2003b)*	*(Ko et al., 2003, Zong et al., 2002, Zeng et al., 2003b, Shenoy et al., 2005a, Zeng et al., 2003a)*

Cellulose Acetate (CAc)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
Acetone/Dimethylacetimide (DMAc) (2:1) *(Ding et al., 2004)* Acetone/water (5-20% wt water) *(Son et al., 2004b)* Acetic Acid *(Han et al., 2008)* Dimethylformamide *(Tungprapa et al., 2007)*	Concentration: ~16% *(Tungprapa et al., 2007)* Molecular Weight: 30,000 *(Han et al., 2008)* Voltage: ~16 kV *(Chen et al., 2008)* Distance: ~15 cm *(Ding et al., 2004)* Electric Field: ~1.3 kV/cm *(Ding et al., 2004)*	Conc.: 3% *(Chen et al., 2008)* - 21% *(Son et al., 2004b)* Conc.: $6.0e^{-4}$ *(Chen et al., 2008)* – $7.0e^{-3}$ *(Son et al., 2004b)* M_w: 30,000 *(Son et al., 2004b)* – 50,*000 (Chen et al., 2008)* Voltage: 8 kV *(Son et al., 2004b)* – 25 kV *(Han et al., 2008)* Distance: 6 cm *(Son et al., 2004b)* – 45 cm *(Chen et al., 2008)* Electric Field: 0.4 kV/cm *(Chen et al., 2008*) – 2.5 kV/cm *(Han et al., 2008)*	*(Ding et al., 2004, Son et al., 2004b, Chen et al., 2008, Han et al., 2008, Tungprapa et al., 2007)*

Gelatine			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
1,1,1,3,3,3 - Hexafluoro-2-propanol *(Li et al., 2006)* 2,2,2 – trifluoroethanol *(Huang et al., 2004)* Acetic Acid, Formic Acid *(Songchotikunpan et al., 2008)*	Concentration: ~10% *(Zhang et al., 2004)* Voltage: ~15 kV *(Zhang et al., 2004)* Distance: ~12 cm *(Huang et al., 2004)* Electric Field: ~1 kV/cm *(Li et al., 2006)*	Conc.: 5% *(Huang et al., 2004)* - 29% *(Songchotikunpan et al., 2008)* Voltage: 10 kV *(Li et al., 2006)* – 28 kV *(Powell and Boyce, 2008)* Distance: 10 cm *(Li et al., 2006)* – 15 cm *(Songchotikunpan et al., 2008)* Electric Field: 0.8 kV/cm *(Huang et al., 2004)* – 1.3 kV/cm *(Huang et al., 2004)*	*(Huang et al., 2004, Li et al., 2006, Zhang et al., 2004, Songchotikunpan et al., 2008, Powell and Boyce, 2008)*

Zein			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
Ethanol/Water (4:1) *(Miyoshi et al., 2005)* Acetic Acid, Isopropyl Alcohol/Water (4:1), Ethanol/Water (3:2) *(Selling et al., 2007)* Dimethylformamide *(Jiang et al., 2007)*	Concentration: ~25% *(Miyoshi et al., 2005)* Voltage: ~20 kV *(Jiang et al., 2007)* Distance: ~10 cm *(Selling et al., 2008)* Electric Field: ~2 kV/cm *(Yao et al., 2007)*	Conc.: 17% *(Selling et al., 2008)* - 50% *(Yao et al., 2007)* Voltage: 8 kV *(Miyoshi et al., 2005)* – 40 kV *(Selling et al., 2007)* Distance: 5 cm *(Selling et al., 2007)* – 25 cm *(Jiang et al., 2007)* Electric Field: 0.5 kV/cm *(Jiang et al., 2007)* – 4 kV/cm *(Selling et al., 2007)*	*(Miyoshi et al., 2005, Selling et al., 2007, Jiang et al., 2007, Yao et al., 2007, Selling et al., 2008)*

Melt Spinning			
Polypropylene (PP)			
Solvents	**Typical Processing Parameters**	**Processing Parameters Range**	**References**
	Polymer Temp: ~285^{o}C *(Lee and Obendorf, 2006)* Molecular Weight: ~200,000 *(Dalton et al., 2007)* Voltage: ~20 kV *(Dalton et al., 2007)* Distance: ~4 cm *(Dalton et al., 2007)* Electric Field: ~ 5 kV/cm *(Dalton et al., 2007)*	Polymer Temp: 200^{o}C *(Lyons et al., 2004)* – 320^{o}C *(Dalton et al., 2007)* M_w: 14,000 *(Lyons et al., 2004)* – 580,000 *(Lyons et al., 2004)* Voltage: 10 kV *(Lee and Obendorf, 2006)* – 30 kV *(Lyons et al., 2004)* Distance: 2 cm *(Lyons et al., 2004)* – 7 cm *(Lee and Obendorf, 2006)* Electric Field: 1.4 kV/cm *(Lee and Obendorf, 2006)* – 15 kV/cm *(Lyons et al., 2004)*	*(Lee and Obendorf, 2006, Lyons et al., 2004, Dalton et al., 2007)*

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