We are always told that if you are serious about macro photography you need to buy a quality macro lens. I would agree up to a point but dedicated macro lenses come at a significant cost. Thankfully there is a more cost effective alternative, a set of extension tubes.

Extension tubes are often wrongly considered as the Cinderella of macro photography and dismissed for serious macro work. Having had over 40 years’ experience using extension tubes as well as many different dedicated macro lenses I strongly disagree. With the right technique you can easily produce images of equal quality to those with much more expensive and dedicated macro lenses. In my view the only real benefit of macro lenses over extension tubes is convenience in that you have just one lens that will focus from infinity to 1 to 1 or life-size magnification. With extension tubes however you do need to change them to achieve different focusing ranges. This is however a very small price to pay for as much as a seven fold saving in costs versus a dedicated lens. (£100 for a set of extension tubes - £700 for a Canon 100mm f2.8 L macro lens).

In many instances it’s even possible to produce images at a higher magnification with extension tubes than with most macro lenses. A true macro lens must focus down to life-size or 1 to 1 magnification. Only very specialist macro lenses go beyond 1 to 1. With the right extension tubes however, any lens – macro or otherwise – can focus much closer and produce a much higher magnification image.

Another very powerful use for extension tubes, discussed below, is to enable telephoto lenses to focus much closer than would normally be the possible. For that reason alone they always have a place in my camera bag.

**How do they work?**

As you approach closer and closer to a subject you have to continually refocus the lens to ensure that the image falls in focus on the digital sensor. In terms of the physics you are adjusting the lens to cause the light rays to bend more and more the closer the subject.
Eventually you reach a point where the light rays can’t be bent anymore and the image falls behind the sensor and is thus out of focus.

![Diagram of object, lens, and sensor](image)

Object too close – lens forms image behind the sensor.

The solution is simple. Move the sensor to where the image is by spacing out the distance between the lens and the camera with hollow metal tubes called extension tubes. The length of tubes you need depends on how far you need to move the sensor. In the past we used a device called bellows which provide continues variation in length. Now we use rigid tubes of fixed lengths which can be stacked to provide different “extensions”. Used with zoom lenses or by simply adjusting the focus on the lens we can achieve the same as we did with much more clumsy and flimsy bellows.

A similar approach allows extension tubes to be used with telephoto lenses to enable frame filling images of timid insects – e.g. dragonflies and butterflies – without approaching close enough to frighten them. This won’t be a 1 to 1 life size image but that’s not what you need. A telephoto lens is great at magnifying the image but has a minimal focusing distance which is far too great to permit frame filling images of such small subjects. If you do get close enough to fill the frame the image will be out of focus as you are closer than the minimum focusing distance and the image is formed “behind the sensor”. Using extension tubes however you can again move the sensor to where the image is and thus obtain a clear focus and shoot butterflies and dragonflies from a “safe” distance and not frighten them away.

**Extension tubes are not the same as extenders!**

I regularly find people confuse extension tubes with tele-convertors sometimes called – confusingly - extenders.

They are not at all the same. A tele-converter is designed to increase the apparent focal length of a lens. For example a 200mm lens can become equivalent to a 280mm lens with the 1.4X tele-convertor or a 400mm with a 2X tele-convertor. This is a very useful technique and I regularly use a 1.4X extender. It does have some disadvantages however and as it’s not a solution for close up photography I am not going to discuss it here. It is true that in some instances extenders can be used with extension tubes but this is an advanced approach not covered here. If you want to know more send me an e-mail and I will try to help.
An extension tube, as stated above, is designed to increase the sensor to lens distance to manage situations where the lens simply won’t focus close enough. The only tradeoffs are that there is a marginal loss of light and you can’t any longer focus on distant objects – more of this below.

Extension tubes are hollow and have no glass elements which is one of their major benefits – there is no glass to interfere with and degrade the image.

**Using extension tubes**

The biggest problem people experience in using extension tubes is finding the range of focus in which they operate. As explained the benefit of extension tubes is that they reduce the minimum focus distance but they also reduce the maximum focusing distance. With extension tubes fitted the lens will no longer focus on infinity. This is not a problem as you are using them specifically to get close and can remove them when you want to return to photographing at a distance. (N.B. Do beware of dust getting into the cameras and onto the sensor when changing lenses.) The issue is however that with this reduced range it’s sometimes difficult for the first time user to find a point where the lens will focus and this is the main reason I find people don’t persist with them and miss out on their real strengths.

My advice is very simply. Extension tubes usually come in sets of 3 different lengths. Start with the smallest you have, usually about 12mm. Remove the lens from your camera, attach (mount) the extension tube on the camera as you would a lens then remount the lens on the extension tube. Without touching the shutter button or focus ring on the lens simply move closer and further away from the object until it comes roughly into focus in the view finder. When you have established this distance, standing still, gently touch the shutter button to force the camera to adjust the fine focus for a perfect shot. You will find that you can adjust the focus manually to move a little closer or a little further away and thus frame the object as you would like. If you are using a zoom lens you will also be able to adjust the zoom to change the magnification. Beware though that if you use the lenses zoom in this way you may also have to move slightly to adjust your distance from the object. Once you have established this “working distance” for this lens and extension tube combination make a mental note of it for the future so that you can easily use it again. If the object isn’t large enough in the view finder (you can’t get close enough) try a longer extension tube and repeat the above.

In addition the effectiveness, or usefulness, of extension tubes (of all lengths) depends on two factors

- the focal length of the lens
- the lenses native minimum focusing distance.

The shorter the lens, and the closer its minimum focal distance, the greater the level of magnification will be gained from adding any combination of extension tubes.

It really is best to practise at home on your dining room table before trying them in the field. After you become
comfortable with them however you will find that they open up a completely new area of photography to you at negligible cost.

For those mathematically minded there are a number of formulae on the internet for calculating these minimum distances but I prefer to learn by experiment and taking five Canon lenses and 3 extension tubes on a wet afternoon in November I came up with the following table. I was using a full frame 1D series camera – note the comments on cropped sensor cameras below. (N.B. This is meant to be a guide only based on my experimentation manufacturers official data – if you can find it - may vary but only slightly)

<table>
<thead>
<tr>
<th>Lens</th>
<th>Minimum focusing distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Native</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Canon 50mm f1.8</td>
<td>0.45</td>
</tr>
<tr>
<td>Canon 85mm f1.8</td>
<td>0.85</td>
</tr>
<tr>
<td>Canon 100mm f2.8 L Macro</td>
<td>0.30</td>
</tr>
<tr>
<td>Canon 300mm f4</td>
<td>1.30</td>
</tr>
<tr>
<td>Canon 100-400 L f4-f5.6 (at 400mm)</td>
<td>2.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lens</th>
<th>Magnification at closest focusing distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Native</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Canon 50mm f1.8</td>
<td>0.15</td>
</tr>
<tr>
<td>Canon 85mm f1.8</td>
<td>0.13</td>
</tr>
<tr>
<td>Canon 100mm f2.8 L Macro</td>
<td>1.00</td>
</tr>
<tr>
<td>Canon 300mm f4</td>
<td>0.24</td>
</tr>
<tr>
<td>Canon 100-400 L f4-f5.6 (at 400mm)</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**Depth of field considerations.**

Depth-of-field is determined by four factors:

- the focal length of the lens
- the aperture
- the distance between the lens and subject.
- the cameras sensor size

When using extension tubes the distance between lens and subject has the greatest effect on depth-of-field. The closer your lens is to your subject, the less depth-of-field you have. When shooting with extension tubes, depth-of-field may be so limited that you cannot obtain front to back sharpness even at f16 or f22. This is true irrespective of the lenses focal length. It is worth noting that this also holds true when using dedicated macro lenses thus is not a problem caused by extension tubes but rather the physics of light and optics.
Furthermore, if you shoot at very small apertures then you risk adding an effect called diffraction. In terms of the physics, very small apertures cause different colours to focus at different places, thus the image may seem a little blurred. There is a solution to this at least for stationary objects and involves a technique called focus stacking. Space is limited here for discussing this but there is a full explanation on my website under the Tips and Techniques section on the menu or by clicking http://www.naturesphotos.co.uk/pages/tips-and-techniques.php#FocusStacking. Here you will find a link to a downloadable 15 page document exploring and explaining the subject in depth.

**Using Cropped Factor Cameras**

Those of you who have heard me speak on macro techniques will know that I firmly believe there are many reasons to use a cropped sensor camera for shooting macro.

*A cropped sensor camera has a reduced size sensor, compared to that on a full frame camera. A full frame camera such as a Canon 1DX has a sensor size of 36mm x 24mm and a Canon 70D for example has a sensor size of 22.5mm x 15mm.*

Magnification is determined by the focal length and the extension of the lens plus tubes, thus you might assume that the sensor size is not relevant. However, in practice, the crop factor does make a difference to the apparent magnification. If you use a full frame lens/camera combination (such as the Canon 1DX in the above table) and configure it to give a 1x or life size magnification then an object that is 36mm x 24mm will fill the viewfinder and cover the sensor. If you use a camera with a cropped sensor – such as the Canon 70D - then an object 22.5mm x 15mm will fill the viewfinder and cover the sensor. The camera will in effect only record the central part of the object, 22.5mm x 15mm (the exact sensor size varies by model). If you compare the two photos side by side at the same printed size then you will see the cropped APS-C sensor 70D has an additional 1.6X (36mm/22.5mm) magnification. This means that an APS-C camera appears to get you closer to your subject than a full-frame camera.

![Shot on a full frame camera](image1.jpg)  ![Shot on a cropped sensor APS-C camera](image2.jpg)

N.B. The above is a simulation created by simply cropping the original photo to demonstrate the point

A further benefit of using a cropped sensor camera is the effect it has on depth of field. As stated above the size of the sensor is one determinant the others being the aperture, lens to subject distance and lens focal length. If you shot a picture on a full frame camera and achieved a magnification of 1 to 1 (life size) then the depth of field would be determined by the aperture. If for example we shot it on a full frame Canon 1DX with a 100mm L series macro lens the subject distance to achieve 1 to 1 would be 0.3m and the depth of field at f22 would be less than 1mm. If however you shot the same image on the cropped sensor Canon 70D camera to achieve frame filling magnification on the smaller sensor you would shoot it from further away (0.48m). In this configuration whilst the magnification is the same the depth of field at f22 would be just over 2mm or more than twice as much.
There are many 3rd party manufacturers of extension tubes on the market all of whom are cheaper than the manufacturers own.

You do however need to be careful however as there are some very cheap ones sold on sites such as e-bay but also by other suppliers such as Amazon which, on closer inspection, you will see are manual only and some are made of plastic. These manual tubes don’t have any electrical contacts and thus you cannot auto focus or “stop down” your lens to use smaller apertures. You will therefore have to focus manually and will be limited to using your lens at its widest aperture so be unable to increase or manage the depth of field. Plastic ones are flimsy and can get stuck on your camera.

The manufacturers own, and some third party ones, have brass contacts to maintain full electrical communication between the camera body and lens to enable you to stop down the aperture and, if you want to, use autofocus. There are many options but in my view few are better than those marketed by a Japanese firm called Kenko - http://www.kenkoglobal.com/.

Kenko don’t sell their products direct but they can be bought through many online sites such as Amazon and are available for Canon, Nikon, Sony, all micro four third cameras and many others. A little bit of hunting on the web can find them for prices as low as £90. Unfortunately at the moment (May 2013) I am not aware of any such third party version for Pentax cameras however.

A cheaper alternative are those made by Polaroid and yet others such as Meike these cost less at around £60. In my experience these are equally reliable but the lens release knobs are a little more fiddly.

**N.B. Canon users**

If using a Canon Cropped Sensor Camera such as the 40D, 50D, 60D, 70D, 400D, 450D, 500D, 600D etc. with EF-S lenses i.e. the ones with a white and red “mount alignment” dot.

then you need to be aware that you will require compatible tubes. Failure to do so **will** damage your lens!

Canon users - If in doubt buy EF-S compatible tubes as they work with both EF-S and the normal EF lenses.
When getting very close!

As explained, there is in principle no limit to how close you can get with extension tubes. Indeed you can even use extension tubes with specialist macro lenses to get closer that they will manage unaided. You can also use extension tubes with highly specialist macro lenses such as Canon’s MPE65 (1 to 5 times magnification macro lens). I have shot up to 15 times magnification with this combination. The spider opposite is about 3 times magnification and the sundew below it about 12 times (on the 36m x 24mm sensor).

As you get very close however by adding more and more extension tubes you eventually reach a point where the lens doesn’t perform properly. This “critical” magnification varies with different lens and extension tube combinations but a rule of thumb is if you are working over 2X or maybe even 1.5X to 1X magnification on some lenses then it might be an issue. The solution however is very simple and uses a technique also often deployed for macro photography namely reversing the lens.

Basically a lens is designed to work best when the subject to lens distance is much greater than the lens to sensor distance as in the top diagram below. In both diagrams the rays of light from the subject to the sensor are shown to demonstrate the relationships between the lens to sensor and lens to subject distances.

In the lower diagram extension tubes have been used to extend the lens to sensor distance and thus permit closer subject to lens and a higher magnification. As can be seen by observing the light ray lines for the reversed lens they are now as the lens designer intended.
Reversing rings are carefully machined metal rings with a lens mount on one end that attaches to the camera lens mount. At the other end is a thread which screws into the filter mount of the reversed lens. You clearly have to buy one to fit a) your camera and b) the filter thread of the lens you intend to use it with but they are reasonably cheap at less than £10 each so you can buy ones for various lens filter thread sizes as required. The diagram (left) shows a lens coupled straight to a camera but in practice of course you would have extension tubes between the lens and the camera.

One clear problem with reversing a lens is that there is no longer an electrical connection to the camera as the gold contacts at the rear of the lens are now facing outwards. As a result,

- autofocus won’t work,
- the aperture will be stuck wide open,
- any image stabilisation in the lens will not work
- also dirt and dust can get into the rear of the lens if you are not careful

The lack of image stabilisation may not be much of an issue and you can manually focus but working at maximum aperture does mean that the depth-of-field is going to be very small indeed. Fortunately there is a “work around” at least for Canon users which will work in most instances.

1. With the lens connected to the camera as normal and with the camera in AV mode, select the required f-stop.
2. Press the depth-of-field preview button (on the front usually beside the lens) and keep it pressed while simultaneously disconnecting the lens. This will close down the aperture in the lens and it will remain at that setting until the lens is reconnected to the camera in the normal way.
3. Reverse the lens on the lens mount. This is easier if you keep the reversing ring screwed into the filter thread in which case you can just turn it around and re mount on the camera.

**Exposure calculation.** This is not an issue as although the camera and lens can’t communicate the exposure meter in the camera will still work since it’s just measuring the amount of light entering the camera through the lens. The camera can’t read the aperture from the lens however so in order to determine the correct exposure, set your camera to manual mode and then adjust the shutter speed and ISO using the inbuilt manual exposure indicator.

**Focusing.** You will need to manually focus of course and the image will be dark as the aperture is permanently shut down which will make focusing difficult but not impossible. You may therefore choose to use continuous lights such as LED light panels to a) provide more light and b) to help you to focus.
An alternative approach if doing a lot of work with a reversed lens is to use an electrical lens coupler or auto reversing ring. These devices perform as a normal reversing ring but have an electrical wire that connects to a second ring that mounts on the rear (now front) of the lens so you retain control of your lens even though it’s mounted back-to-front.

These devices used to only be made for Canon and then only by a company called NovoFlex at about £350 but more recently others have started to sell them much cheaper - £50 from Meike. It’s still very difficult to buy non Canon ones but is occasionally possible. Any budding electronic engineer or DIY enthusiast whose good with a soldering iron can however make one using two extension tubes and a short piece of cable. I found this example (right) albeit for Canon on the web but the principle would work for any camera.

**Limitations of extension tubes**

There are very few practical limitations to the use of extension tubes. The only real issue with them versus using a dedicated macro lens is that of convenience. With a dedicated macro you can focus from close up out to infinity without changing anything. With extension tubes you have to add and remove them.

The big advantage of extension tubes – apart from cost - is that they can be used with nearly any lens and can achieve magnifications not possible with all but very specialist macro lenses. They can even be used with dedicated macro lenses to improve on the magnification further and all without any loss in the quality of the image. As explained above they can also be used with telephoto lenses to allow you to produce frame filling shots of timid insects such as dragonflies and butterflies without approaching too close.

One often quoted disadvantage is light loss. It is true that adding an extension tube reduces the amount of light reaching the digital sensor thus you need to increase the exposure by increasing the ISO, using a slower shutter speed or setting a wider aperture. However with modern digital cameras coping much better with high ISO’s than those of just a few years ago and certainly better than film ever did, this is no longer an issue. Light is much more of an issue in all aspects of macro be that using extension tubes or dedicated lenses. You are photographing something small which reflects less light and is often in a poorly lit location. To solve this you need to employ additional lights, work in a brighter location or use a dedicated flash. I will be covering this in a future article on my website. In practice however for all except extremely long extensions this won’t be an issue.