Guide to UV LED Curing
Considerations for Converting Process
Engineers and Managers/Owners

INTRO

Ultraviolet (UV) curing processes are already commonly used within wide web converting processes. Recently we are seeing new UV LED curing technology being utilized in converting applications. This guide aims for a better understanding of UV LED installations for curing in converting operations. Be curious about adoption trends, comparison different UV LED systems, maximize production rates optimization, and about making better decisions using total cost of ownership analysis and return on investment calculations.
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<td>3</td>
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UV LED Curing Adoption Trends in Converting Applications

Process development engineers and R&D alike are using Heraeus Noblelight’s application labs globally, application engineering expertise, assistance finding suitable chemistry and locations for line trials, plus free use of UV LED curing loaner equipment for testing and trials to develop successful UV LED curing production processes.
The first converting processes adopting UV LED curing are those that already have a suitable chemistry available.

UV LED’s monochromatic wavelength output (365nm or 385nm) is similar to iron additive UV curing lamps. So converting processes already using iron additive arc lamps are suitable for UV LED curing.

**Figure 1**

<table>
<thead>
<tr>
<th>Wavelength in nm</th>
<th>Irradiance (AU)</th>
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<tbody>
<tr>
<td>440</td>
<td>1</td>
</tr>
<tr>
<td>320</td>
<td>0.8</td>
</tr>
<tr>
<td>340</td>
<td>0.6</td>
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<tr>
<td>360</td>
<td>0.4</td>
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<tr>
<td>380</td>
<td>0.2</td>
</tr>
<tr>
<td>400</td>
<td>0</td>
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</tbody>
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**APPLICATIONS USING UV LED CURING**

- Laminating
  - Packaging
  - Electromagnetic shielding
  - Blister packaging
  - Barrier & Heat resistant films

**More Applications**

- Electronics nanoimprint lithography (NIL)
- Micro and nano patterning
- Processes where UV energy can pass through a substrate such as a transparent film to reach the chemistry beneath

**Hydrogels**

- Biomedical electrodes
- Drug delivery patches
- Wound care dressings
- Cosmetic treatments

**Combination Curing**

Pairing UV LED curing with existing UV curing can be an ideal solution for producing a wide variety of converted products on a single line.
UV LED curing reduces downtime:
/ at the start of a shift or shift turnover
/ production line stops/restarts due to other production process needs or maintenance/less unexpected downtime for maintenance.

UV LED curing systems can cure heat sensitive materials not previously possible. And UV LED dimming controls let you choose exactly the UV energy needed for changing production needs. In addition to less product waste, increased production flexibility and control expands your production capabilities to new products and delivers higher converting line utilization resulting in higher production rates.

Most converting production lines that replace arc lamps with UV LED curing systems will increase production rates by at least 10%.

Semray’s modular plug & play platform saves maintenance time – exchange a segment in 9 sec vs 5 min for competitors’ products.
Instant on/off + 10 x longer useful life + Less maintenance time = 10–50% downtime reduction

Less product waste + Expanded product capabilities + Higher converting line utilization =

30–70% less energy + Lower maintenance =

Lower Operating Costs

Higher Productivity Level

Profit
Adopting a new technology can be risky, but the opportunity to **increase production rates by at least 10%** and reduce operating costs by retrofitting or adding UV LED curing to your converting line can’t be ignored. Choosing the right UV LED system provider is key to minimizing downside risks and ensuring Return on Investment (ROI).

Let Heraeus Noblelight support your process development and feasibility analysis for the potential of UV LED curing on your converting lines.

**You’ll gain faster results with less risks.**
If you are dealing with converting processes, read How to Accurately Compare UV LED Curing Systems to learn how to make legitimate comparisons (never rely on equipment specifications!). This will help you choose a UV LED curing system for your specific converting process. Or learn more about the interaction of working distance and uniformity across a web and the impact on production rates by reading The Uniformity versus Production Rate Conundrum.

If you are a converting manufacturing manager or owner, learn how UV LED improves Total Cost of Ownership (TCO) compared to arc lamps. Or read about capability expansion and machine utilization, two important factors to include in your UV LED curing ROI calculations.

Use this Guide to learn more about how to get started and what to consider when choosing a UV LED curing system provider who can help you assess feasibility and production rate improvements for your converting manufacturing operations.

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How to Accurately Compare UV LED Curing Systems

It can be difficult and confusing for process design and development engineers to accurately compare different UV LED curing systems for their converting production process due to several factors. First, there is are no UV LED curing equipment specification standards. Secondly, comparisons are further complicated because UV LEDs require different radiometry measuring devices from those used with traditional UV curing technology.

In this article you’ll learn which UV LED curing equipment specifications are important for evaluating and comparing different systems and how to properly measure UV LED output. Equipped with this knowledge you can make legitimate comparisons and the best decision when choosing a UV LED curing system for your specific converting process.

End users often compare UV LED curing systems based on electrical power input, radiant power output, and the resulting efficiency. However, what is useful for an optimal converting process, such as the UV curing of laminating adhesives, hydrogels, and nanoimprint lithography, is information and comparison values about the intensity, uniformity, and distribution of the UV radiation onto the substrate. Converting process engineers should to know what to measure and how to obtain accurate measurements for comparing the production performance of different UV LED curing systems.
Manufacturers of UV LED curing systems usually specify peak power density at the exit or emission window. However, these values are misleading and unsuitable to obtain information about curing effectiveness on the substrate. A UV LED curing system with high peak values may not have a very uniform radiation distribution, resulting in uneven curing. Moreover, peak values depend on the choice of measuring instrument. For example, measuring results for short distances (less than 25 mm) can be influenced by the instrument’s detector properties and therefore difficult to compare at all.

Mean power density is determined by dividing the total radiated power (W) by the emission window area (cm²). The resulting units are described in W/cm², but should not be confused with irradiance, whose units unfortunately are also W/cm²! That means both peak values and mean power density are specified in W/cm², but the values refer to different output variables and are therefore not directly comparable.

Let’s look at a real example. Heraeus’ independent and accredited measuring laboratory measured and compared the mean power density of three different UV LED curing systems. The total radiated power was determined by means of goniometry and the window area (cm²) provided by the product technical data. Fig. 3 shows major differences in mean power density even though all three devices were specified as the “same” 8 W/cm².

For the systems measured, the radiated power in proportion to the window size varies between 4.0 and 6.9 W/cm².

Figure 3
In addition to the mean power density of the UV LED curing systems, the available or useful UV irradiance is decisive for a production process. Not all UV LED curing systems control and focus the output in a way that maximizes converting production. Heraeus’ Semray® UV LED curing system uses special micro-optics to shape the beam, concentrating the radiant energy onto the substrate where it is needed for curing and reducing wasted or stray radiation. The result is higher useful irradiance and less loss delivering an optimal and efficient curing process. Systems with specifically adjusted micro-optics have very high irradiance values even at large distances from the working surface. Fig. 4 illustrates the benefits of micro-optics on forward irradiance.

**Figure 4**

Learn more about the interaction of micro-optics on uniformity across a web and production rates by reading The Uniformity versus Production Rate Conundrum.
In spite of the limitations of various measuring devices and the variation in any individual measurement value taken with different instruments, with proper techniques we can use these values to make comparisons and set-up and monitor a UV LED curing process. The measurement instruments are simple to use and designed for various purposes. To obtain reliable and, above all, comparable measuring results, specific requirements must be met:

- The measuring instrument should have a flat spectral sensitivity, the red line shown in Figure 5, with an appropriate calibration. A device calibrated for mercury arc lamps is not suitable to measure UV LEDs.
- UV LEDs require special measuring instruments.
- The measuring instrument must have a cosine response to measure radiation impinging on a surface from all angles. The measuring instrument must be able to measure high intensities and also withstand high temperatures.
- The third important parameter is the precise determination of the measuring distance, i.e. the distance between UV LED source and measuring instrument detector.

The two most important values impacting curing are typically peak irradiance (W/cm²) and total energy (J/cm²), sometimes referred to as dose, which takes into account exposure time. For a specific curing process these measurements need to be taken at the substrate, not the emission window of the UV LED curing unit. End users should take radiometry measurements, using the correct radiometry measurement device for UV LED curing, to compare different curing systems and characterize the curing parameters for their process. Learn more about correctly measuring output of UV LEDs by downloading Technical Paper: Comparing traditional UV to UV LED.
Even though a UV LED curing system specification is 8W, 8W are not always delivered! Uniform terms and appropriate measuring instruments and methods provide accurate data to compare which UV LED curing system will be best suited for your converting process. Your final UV LED curing system decision should be based only on tests carried out under real process conditions.

Heraeus Noblelight’s experienced UV curing application experts are available at our Gaithersburg, MD application center to help you understand measurement techniques and the curing parameters for your converting UV LED curing process.

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**The most important radiometry and metrological terms:**

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RADIATED POWER/RADIANT FLUX</strong></td>
<td>Entire power emitted by radiation; unit: watt (W)</td>
</tr>
<tr>
<td><strong>IRRADIANCE</strong></td>
<td>Radiated power arriving on a unit of area; unit: W/cm²</td>
</tr>
<tr>
<td><strong>RADIANT EXPOSURE/DOSE</strong></td>
<td>Time integral of irradiance over a certain period of time; unit: J/cm²</td>
</tr>
<tr>
<td><strong>MEAN POWER DENSITY AT THE EXIT WINDOW</strong></td>
<td>Total of radiated power (W) / window area (cm²); used to compare UV-LED systems, resulting units are W/cm²</td>
</tr>
<tr>
<td><strong>POWER DENSITY (PEAK VALUE)</strong></td>
<td>Typical data to describe the power output of devices; means the max. irradiance directly at the exit window; unit: W/cm²</td>
</tr>
<tr>
<td><strong>GONIOMETRIC MEASUREMENT</strong></td>
<td>A detector is moved around the radiation source in such a way that its entire radiated power can be captured; result = radiant power</td>
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</table>
Attention: W/cm ≠ W/cm²

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/CM</td>
<td>Describes medium-pressure lamps in electrical watts divided by bulb length</td>
</tr>
<tr>
<td>W/CM²</td>
<td>Describes the unit of irradiance or mean power density of UV-LEDs</td>
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UV LEDs used at close distances have poor uniformity, but increasing working distance to improve uniformity decreases energy density on the substrate. And less energy density on the substrate means slower converting line speeds, reducing production rates. This is the conundrum you as a process engineer must address to ensure UV LED curing installed on your converting line delivers the maximum production rates possible. Read on to learn how working distance, output uniformity, and energy density of a UV LED system interact with each other and how to maximize production rates.

Working distance is the distance from the face of a UV curing system to the substrate surface. UV energy reaching the substrate drops significantly the larger the working distance, even more so with UV LED curing systems which emit energy from the emission window at high angles. So it is advantageous to place the UV LED curing units close to the web material to get maximum energy density onto the substrate and thus faster line speeds. However, at close distances, 5 to 10 mm commonly used in printing applications, the uniformity across the web width is poor. You also risk damage to the UV emission window (and the product) should the web material come into contact and it’s more likely to contaminate the emission window with coating or adhesive.

UV LEDs do not use reflectors internally since the energy is all forward facing. Some UV LEDs incorporate external mirrors, glass rods, etc. or internal micro-optics as a means to better control and enhance the output onto the substrate.
Micro-optics used in Semray UV LED curing systems focus the energy enabling converting line working distances of 20 to 30 mm to ensure uniformity across the web width without reducing energy density significantly. This results in reduced contamination of the emission window, thus a more consistent process with increased uptime.

UV LEDs can be used on lines up to 90 inches wide. UV LED curing system manufacturers either make an array of the length you need or combine smaller arrays of UV LEDs into a single system that can span the width. For example, Semray’s modular plug and play UV LED curing platform (watch the video) uses 3-inch wide segments that mount into a housing or backplane. The backplane has the power and controls and can contain enough segments to span a 90-inch wide converting line.
Curing uniformity across the web is important for ensuring product consistency. You are probably already aware that as an arc lamp ages the lamp ends darken decreasing the uniformity of UV energy output across its length, i.e. the width of your converting line. This means you have to change lamps often or risk increasing scrap rates.

With UV LED curing, uniformity across the web width depends on the specific curing equipment chosen, but as shown in the graphic uniformity is generally better the further away the emission window is from the web material (shown in the middle). Too close and there tend to be “hot spots” as well as areas that may not be sufficiently cured (shown at the top). Most converting lines place UV LEDs 10 to 30 mm from the web and require UV LED curing systems with specialized optical control to ensure high UV energy density and the highest line speeds (shown at the bottom).

Figure 7
In addition to Semray’s micro-optics mentioned earlier, self-monitoring sensors dynamically adjust the LEDs to maintain consistent energy output. And every segment (consisting of 3 channels) is calibrated before shipment with an accuracy of +/-2% (which is within the measuring tolerance of most UV meters). With this balancing (calibration) users of Semray can achieve an overall uniformity within a large system of +/-5%.

Read How to Accurately Compare UV LED Curing Systems to learn how to make legitimate comparisons (don’t rely on equipment specifications!) and the best decision when choosing a UV LED curing system for your specific converting process.
INTRO

Making an investment decision about new UV curing equipment for your converting operations should be based on solid facts. One of the best ways to substantiate the investment decision and compare UV curing equipment suppliers with differing offers is to assess the total cost of ownership (TCO).

TCO helps you understand better the costs over and above the purchase price by looking at the cost of acquisition, operating costs, and costs related to upgrades and expansions.

It is important to keep in mind that usually the first cost represents less than 10% of the total cost spent on a piece of equipment over its lifetime. In fact, energy costs, maintenance, and repair fees can have at least five times more relevance than the upfront cost, but few consider these factors as part of the price during their selection process.

What originally seemed like a good purchase price can turn out to be a financial and operational nightmare due to hidden costs like maintenance, downtime, and system upgrades.

Taking time now to discover and assess these hidden costs via a TCO analysis will help you make the best investment decision with the highest return on investment for new UV curing equipment options such as arc lamps and UV LED.
Total acquisition costs include everything needed to get the UV curing system installed and operational on your converting line including the following.

**WEIGHING**

**ACQUISITION COSTS: ARC LAMP VERSUS UV LED CURING**

Remember that first cost is only about 10% or less of the total cost of ownership.

**FACILITIES INSTALLATION COSTS**

The costs to install the electrical supply, cooling and exhaust fans, light shielding and other facilities related items are significantly less for UV LED curing systems.

**INSTALLATION**

The costs to train operators and maintenance personnel is about equal for either type of UV curing system.

**TRAINING**

**SEMRAY® ADVANTAGE:**

Heraeus’ provides on-site installation and training for your team to ensure your converting line is up and running as quickly and safely as possible. The Semray® plug and play platform offers internal cooling and simplified electrical supply and controls for lower cost, faster integration onto your converting line.
Overall operating costs of UV LED systems are significantly less than arc lamp curing. Read more details about how UV LED curing drives down costs to deliver ROI.

Financial standing, reputation, and service capabilities of a supplier are important over the operating life of the UV curing equipment. You’ll need quality service and availability of consumable and spare parts from a UV LED curing supplier for 10 years or more.

<table>
<thead>
<tr>
<th>COST FACTORS</th>
<th>ARC LAMP SYSTEM</th>
<th>UV LED SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Chemistry</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Energy</td>
<td>$</td>
<td>$</td>
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<tr>
<td>Spare Parts</td>
<td>$</td>
<td>$</td>
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<tr>
<td>Floor Space</td>
<td>$</td>
<td>$</td>
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<tr>
<td>Downtime</td>
<td>$</td>
<td>$</td>
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<tr>
<td>Scrap Rates</td>
<td>$</td>
<td>$</td>
</tr>
</tbody>
</table>

**SEMRAY® ADVANTAGE:**
The unique Semray® plug and play platform delivers less maintenance and downtime compared to competing systems. Plus take advantage of consignment inventory to lower spare part costs even further.

Figure 10
When considering the installation of UV LED curing, the main consideration here is to compare the cost differential between suppliers for upgrades or expansion of your UV LED curing system. The reason is that upgrades can be a major hidden cost you’ll face sooner rather than later because UV LED technology advances rapidly as shown in the chart.

To take advantage of the technology improvements which result in faster line speeds, and stay ahead of your competitors, you’ll need to upgrade and/or expand your UV LED curing equipment. So TCO of any UV LED curing system depends on how expensive it is to upgrade and expand. Some UV LED curing systems require complete replacement of the electrical supply and controls, cooling system, light shielding, and other system components which drives upgrade costs higher. The same situation may apply for expansions where you want to expand the width of cure across the web.

**Figure 11**

<table>
<thead>
<tr>
<th>Year</th>
<th>Watts/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>2</td>
</tr>
<tr>
<td>2010</td>
<td>4</td>
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<tr>
<td>2012</td>
<td>6</td>
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<tr>
<td>2014</td>
<td>8</td>
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<tr>
<td>2016</td>
<td>10</td>
</tr>
<tr>
<td>2017</td>
<td>12</td>
</tr>
</tbody>
</table>
By continuously striving to improve performance and finding more efficient ways of doing things, like adding UV LED curing, your converting operations can reach higher production rates with higher yield rates and profitability than your competitors.

Managers and owners who use TCO, not acquisition costs alone, will make better decisions when it comes to buying UV LED curing equipment for their converting operations.
Semray’s modular plug & play platform enables easy and less costly upgrades and expansion for a clear competitive advantage. To take advantage of new LED chip technology, simply replace arrays within a segment, not the entire segment. Heraeus’ service team is on hand to make upgrades fast and simple, so it’s easy for you to keep pace with progress. And to expand to wider width curing, say to respond to new customer requirements, just add additional segments into the backplane already installed on your converting line.

Learn more details about how UV LED curing drives down costs and increases revenues to deliver ROI. Understand more about UV LED curing adoption trends in converting applications.
ROI: Driving Down Costs and Increasing Revenues with UV LED Curing

Supplementing or replacing arc lamp UV curing with UV LED curing on a converting line offers advantages that deliver a significant return on your investment (ROI). Converting manufacturing managers and owners need to understand the elements of cost savings and increased revenues contributing to ROI for installing UV LED curing.

Managers and owners need to calculate the ROI before making the final decision and, in most cases, to get budget dollars approved. Let’s discuss some of the most common factors that contribute to ROI.

You’ll need to calculate the impact for your specific situation, but use the list below as a reference guide when calculating ROI for installing UV LED on a converting production line such as laminating, hydrogels, or nanoimprint lithography lines. It’s important to factor in both the cost and revenue impacts.

$$\text{ROI} = \frac{\text{NET PROFIT}}{\text{COST OF INVESTMENT}}$$
THE COST SIDE

You need to account for the first costs, both the equipment and the costs to install UV LED curing, and on-going operating costs.

FIRST COSTS

UV LED curing equipment cost – While the cost of UV LED curing equipment is higher than arc lamp equipment, it is offset somewhat by lower facilities related costs (see below). And with an increasing trend towards more widespread adoption and increased volume, prices of UV LED curing systems have decreased significantly, dropping about 20% over the last decade.

Initial facilities costs – The changes you have to make to existing production lines and facilities can be significant with arc lamp UV curing systems, but are much simpler or nonexistent with UV LED systems. For example, there’s no need for cooling & exhaust blowers or ducting with UV LED since cooling is integral to the system you purchase. Electrical supply, light shielding, etc. are also much less. So if you are comparing ROI of installing an arc lamp system versus a UV LED system, be sure to account for this cost difference.
Formulated chemistry costs – Most UV LED curable chemistries do cost more than their equivalent arc lamp chemistries, but be sure to ask your formulator or supplier for costs based on projected volumes. We should see a similar downward price trend as we’ve seen with UV LED equipment as UV LED curing becomes more and more prevalent.

Substrate material costs – Because it is easier to control UV LED curing processes, overall reliability improves reducing scrap rates. So there will be a reduction in costs of substrate materials such as film, paper, and foil. Likewise you may find you use less formulated materials like adhesives.

Energy costs – UV LED curing systems typically offer 30 to 70% energy savings compared to arc lamp curing. Work with your local electric utility and your UV LED equipment supplier to estimate these cost savings. Be sure to include savings from reduced cooling/exhaust fan energy and, if appropriate, impacts on conditioned spaces.

Maintenance costs – UV LED systems require significantly less maintenance than arc lamp systems since there are no reflectors, ballasts or shutters, have essentially maintenance-free cooling fans, and significantly fewer lamp changes since LED’s last up to 10 times longer.

Ongoing consumable parts costs – Typically costs related to consumable and spare parts such as lamps, reflectors and ballasts diminishes significantly with UV LED curing since there are no reflectors or ballasts and lamps last longer.

SEMRAY® ADVANTAGE:
Heraeus’ Semray® UV LED plug and play platform reduces maintenance costs even further – it only takes 9 seconds to exchange a segment compared to 5 minutes for the competitors’. Plus Semray’s on-board diagnostics enable quick troubleshooting and even less maintenance time.
The most obvious impact on revenue is increased production rates due to faster line speeds when using UV LED curing for your existing converted products. But don’t forget to consider the following as well.

All together most converting production lines that replace arc lamps with UV LED curing systems will increase production rates by as much as 10% or more.

**Higher yield rates** – Typically converters using UV LED curing find their scrap rates go down compared to production using arc lamps because the UV LED process is better controlled and can start/stop instantly with the needs of the production line. This lower scrap rate translates into higher yield rates with UV LED curing.

**Less downtime** – Compared to arc lamps, UV LED curing systems reduce downtime, both planned and unexpected, by 10% to 50% or more due to their reduced maintenance requirements, instant on/off capability, 10 times longer useful operating life, and quicker set-up times between production runs.

**Minimum downtime due to revolutionary plug & play concept**
**Expanded products** – UV LED curing systems operate at much cooler temperatures than traditional UV curing enabling you to run heat sensitive materials not previously possible. In addition to higher machine utilization (see below), some of these heat sensitive products may offer higher profit margins than existing products and expand your customer base. Assuming there is space on your line, adding UV LED to existing traditional UV curing can provide further flexibility for producing new products. Contract coaters/manufacturers and toll coaters in particular can benefit from the added flexibility UV LED curing offers.

**Higher machine utilization** – How much your converting line is used is a typical manufacturing performance metric. Replacing an arc lamp curing system with UV LED or adding UV LED curing will increase production flexibility to run more products, thus increasing machine utilization. Higher machine utilization indicates higher production rates and makes better use of your existing assets.

UV LED curing offers many tangible benefits to converting production lines that translate into significant ROI as discussed here. Contact us to get started with feasibility testing and gathering the information you need to evaluate the ROI of UV LED curing for your converting operations.

Learn more about total cost of ownership (TCO) of UV LED versus arc lamps at chapter 4.